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DIV. OF WATER &
LAND DEVELOPMENT

January 8, 1987

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Dr. Takeshi Yoshihara
Energy Division
Department of Planning and
Economic Development
State of Hawaii
335 Merchant Street, Room 110
Honolulu, Hawaii 96813

Dear Dr. Yoshihara:

Subject: Study to Integrate Hawaii's Water and Energy Resources

In accordance with our contract, enclosed are two (2) copies of the draft Final Report for the Study to Integrate Hawaii's Renewable Energy and Water Resources. By copy of this letter, we are forwarding two separate copies to Mr. Manabu Tagomori of the Division of Water and Land Development.

We are anxious to receive your review and comments, and look forward to discussing the findings at our meeting scheduled for January 19.

Sincerely,

Maurice H. Kaya, P.E.
Project Manager

Enclosures

cc: Mr. Manabu Tagomori, Encs. (2)

HNB8/090

DRAFT FINAL REPORT

A STUDY OF INTEGRATING HAWAII'S ENERGY AND WATER RESOURCES

CH2M HILL NORTHWEST, INC.
JANUARY 1987

HNB8.063.1

Section S
SUMMARY

This study was performed to determine the economic and technical feasibility of combining renewable energy and water resources development in Hawaii. The study included a general overview of water needs and the use of renewable energy technologies on all the islands. The main emphasis of the study, however, was to evaluate the feasibility of using excess off-peak geothermal energy on the island of Hawaii to develop the water resources on that island. Several potential integrated water/renewable energy projects were identified, and two projects were selected for conceptual planning.

The project findings are summarized in Section S.1. Conclusions reached based on the study and recommendations for further actions are presented in Sections S.2 and S.3, respectively.

S.1 PROJECT SUMMARY

S.1.1 WATER RESOURCES ASSESSMENT

Current water use and future water needs were evaluated for Hawaii, Maui, and Oahu. The total current water use on the Big Island is about 260 mgd. Domestic uses account for 7 percent of the total with agricultural uses making up the remaining 93 percent. Surface waters provide 59 percent of the supply and groundwater provides 41 percent. Nearly three-fourths of the water used on the island is used in the Hilo area, which is on the wet, windward side of the island.

The areas with the greatest need for additional water for domestic uses are the Kona and South Kohala areas, which are on the dry, leeward side of the island. These areas are projected to experience significant resort growth in the near future. The need for an additional 34 mgd of domestic water supplies has been projected for these areas by the year 2000.

The Hilo area is projected to need an additional 4 mgd, and the southeast area of the island will need an additional 2.0 mgd for domestic uses by 2000. There is also a potential need for additional irrigation water on Hawaii. A projected 177-mgd need has been identified, with the majority of this being for "prime-if-irrigated" lands near Waimea.

Water use on Maui is dominated by sugar cane and general irrigation, which uses about 97 percent of the total current use of 612 mgd. Domestic use is about 21 mgd. Additional

Maui water requirements for the future include domestic water needs in the Makena-Kihei region, the West Maui area from Kaanapali to Honokahua, and the Kahului-Wailuku district.

Oahu has the largest population of the islands, and currently requires an average of 135 mgd for domestic uses. Agriculture also uses a large quantity of water. It has been projected that an additional 77 mgd will be required for domestic use by the year 2000. Domestic use is estimated to increase even further, by 89 mgd, by 2020.

The Big Island receives plenty of rainfall, but it is not evenly distributed. The windward side near Hilo receives up to 300 inches per year, while the leeward side near Kawaihae receives less than 10 inches. An estimated 44 percent of the rainfall is used by evapotransporation. Surface runoff accounts for about 25 percent of the rainfall, and percolation to groundwater for about 31 percent. Streamflow and groundwater are both available in large quantities. However, they can be expensive to collect and transport to where needed. The use of low-cost renewable energy can help reduce the cost of developing these resources.

The northeastern coastal area of Hawaii, from the Kohala Mountains to the Wailuku River, has excess surface waters that would be adequate to provide the water needed in the Kona and South Kohala areas. Most of the other areas of the island do not have perennial streamflow. Groundwater, on the other hand, is widespread throughout the island. However, near the coast it can be brackish and in other places the pumping lifts are too high for economical wells.

The surface water conditions on Maui are similar to those on the Big Island. Large quantities of water are available on the wet windward side of the mountains. Much of this water is now collected and transferred by gravity flow for use in dry areas. Additional surface waters are still available for development; however, longer transport distances and/or pumping will be required to develop the resources. Groundwater development has been occurring on Maui for many years. Additional resources could be developed if economical power were available.

It has been projected that water demands on Oahu will approach the potential average yearly supply of the island by the year 2000. Because of steep topography and fairly porous soil conditions, little additional surface water development is anticipated. Groundwater occurs as basal, dike, confined, and perched water, and is the principal source of domestic water. Developing this groundwater requires energy for pumping, which could be provided by renewable energy resources.

Potential sources of water to provide the Kona and South Kohala future water needs are identified in the study. Major surface water sources are the Wailuku River and perennial streams along the Hamakua coast. Major potential groundwater sources that were identified are as follows:

- Potable and brackish basal groundwaters located in the Hawi to Keahole area
- Potable basal groundwater in the Waipio to Kukaiau area
- Potable and brackish basal groundwaters in the Keahole to Hookena area
- Potable basal groundwaters in the Laupahoehoe to Kapoho area

Institutional and environmental considerations will constrain how water resources can be developed. An environmental impact statement and various permits would be required for large water resource development projects. On Oahu, which is so dependent on groundwater, specific government approval is required for developing new groundwater sources in some designated areas. On Hawaii and Maui, however, no controls other than notifying agencies on the location, amount, and use of the water, currently exist.

S.1.2 RENEWABLE ENERGY RESOURCES ASSESSMENT

Several renewable energy technologies have been identified that can rely on resources indigenous to Hawaii and that are in current use or expected to be ready for large-scale commercial use by 2005. These are:

- Geothermal
- Ocean thermal energy conversion (OTEC)
- Wind
- Solar, via thermal energy conversion (STEC) and photovoltaics
- Hydroelectric and pumped storage
- Biomass and municipal solid waste conversion

These technologies were evaluated and, with the exception of solar photovoltaics, appear generally suitable for use in developing water resources. Geothermal, hydroelectric, and pumped storage appear to have especially good feasibility. Geothermal is a well-proven technology; large amounts of energy production are expected to be possible on the Big Island, and development costs are reasonable. Hydroelectric and pumped storage are especially good if incorporated into the water resources project.

The planned use and development of the Big Island geothermal resource was evaluated to estimate the energy that may be available for water resources development. Two scenarios were considered to indicate the range in geothermal energy that could become available. A 50-MW geothermal project for just the Big Island and a 500-MW project that would include the deepwater cable to serve Oahu were considered. Year 2000 average hourly power demands and oil-fired and geothermal generation capacities were evaluated. Based on the scenarios assumed for this study, it was estimated that 120,000 MWh per year of energy would be available from a 50-MW geothermal project. An estimated 1,000,000 MWh per year would be available from a 500-MW geothermal project. These estimates were developed assuming that the geothermal generation would continue all day at full capacity and that excess energy not needed during off-peak demand periods would be available for water resources development.

A graph was prepared and is presented in Section 4 to indicate the amount of water that could be pumped with the excess energy. For example, the excess energy from the 50-MW geothermal project could lift 20 mgd about 3,000 feet. The 1,000,000 MWh per year of excess energy from the 500-MW project could lift 80 mgd about 6,600 feet, which is equal to the difference between sea level and the highest elevation of the Saddle Road between Mauna Loa and Mauna Kea.

S.1.3 CONCEPTUAL PROJECTS

Twelve potential integrated water/renewable energy projects are identified in Section 5. These projects would each use excess geothermal power developed in the Puna area of the Big Island. The water would be used for domestic and/or agricultural needs in the dry west coast portions of Hawaii. Two general categories of projects were developed. Alternatives W-1 through W-4 would use the excess geothermal energy to collect water on the wet side of the island and move it to the dry side where it is needed. Alternatives E-1 through E-4 would transmit the energy to the dry side of the island to be used in developing local groundwater supplies. Four combination projects were also developed utilizing features of both transmitting the energy long distances, and then developing local water sources and transmitting the water to areas of need.

Alternatives W-1 and E-1 were selected and then slightly modified and renamed for more detailed analysis. Project 1 would collect 20 mgd of water from the Wailuku River on the windward side of the island, and then use excess geothermal energy to pump the water over the saddle for use on the leeward side of the island. Raw water would be taken from the river at approximately the 3,000-foot elevation and would then be treated to make it suitable for domestic use. The water would be stored in a covered reservoir as it is treated, and would then be pumped over the saddle during the off-peak energy demand period. A second storage facility would be located on the saddle between Mauna Loa and Mauna Kea at elevation 6,600 feet. The water would flow by gravity from the Saddle Reservoir to the South Kohala coastal area for domestic use. A lateral pipeline would also be provided to provide some water to the Waimea area for domestic and agricultural uses. A third storage reservoir would be provided at the end of the transmission pipeline to provide flow equalization to match local hourly water demands. The project would include approximately 50 miles of pipeline and eight large pump stations.

Project 1 was evaluated as two suboptions. Suboption 1A would not include hydroelectric power generation, and Suboption 1B would include hydroelectric power generation as the water flows from the Saddle Reservoir to the Distribution Reservoir. About 10 MW of power could be developed by the hydroelectric power plants.

Project 2 would consist of developing wells along the island's northwest coast to serve local water needs. The excess geothermal energy would be used to operate the wells during off-peak energy demand periods. The water collected from the wells would be chlorinated and then stored in storage tanks at each well so that the water could be delivered as needed to match hourly demands. It was assumed that 20 wells would be required to provide 20 mgd, and that they would be located at approximately one-mile intervals near elevation 1,300 feet. Each well would have a 2-million-gallon storage tank. Each well pump would be about 400 hp in size.

Existing and planned electrical transmission facilities on the Big Island were reviewed with respect to the project's power needs and power generation. It appears that the existing transmission facilities could be used and that only interconnection facilities would be required.

S.1.4 CONCEPTUAL PROJECTS EVALUATION

Table S.1 summarizes the estimated costs and energy use of Projects 1 and 2. Project 1A, which does not include hydroelectric power generation, would cost an estimated $145 million to construct. There is little opportunity for staged construction in Projects 1A and 1B. Treating the water and pumping it to the top of the saddle would require about 158,000 MWh per year of energy. With energy costing 3 cents/kWh, the total annual O&M cost would be $6.3 million and the delivered water would cost an estimated $2.79 per thousand gallons. This water cost is much higher than the current County of Hawaii Department of Water Supply charges, which are \$0.89 per thousand gallons for the first 5,000 gallons, and \$1.04 per thousand gallons thereafter. If the energy costs 12 cents/kWh, the cost of water would increase to \$4.59 per thousand gallons.

Project 1B, which includes hydroelectric power generation, would have a somewhat higher initial capital cost of \$164 million. This project would generate an estimated 83,000 MWh per year, so the net energy use would be 75,000 MWh per year. The cost of water would be \$3.09 per thousand gallons at 3 cents/kWh and \$3.83 per thousand gallons at 12 cents/kWh.

Project 2 construction cost is estimated to be \$45 million. This construction could be staged over several years as the wells are installed to match the growing water needs. The total O&M cost is estimated to be \$2.1 million, and the cost of water is \$0.71 per thousand gallons if the energy cost is 3 cents/kWh. The annual O&M cost increases by \$4.4 million to \$6.5 million if the energy cost increases to 12 cents/kWh. The water cost at 12 cents/kWh is estimated to be \$1.20 per thousand gallons.

Table S.1
CONCEPTUAL PROJECTS COSTS AND ENERGY USE

Project	Initial Capital Cost (\$ Million)	Total Annual[1] O&M Cost (\$ Million/yr)	Net[1] Energy Use (1,000 MWh)	Water Cost (\$/1,000 gal)
1A, w/o hydro, 3¢/kWh	145	6.3	158	2.79
1A, w/o hydro, 12¢/kWh	145	20.6	158	4.59
1B, w/hydro, 3¢/kWh	164	4.3	75	3.09
1B, w/hydro, 12¢/kWh	164	11.0	75	3.83
2, 3¢/kWh	45[2]	2.1	48	0.71
2, 12¢/kWh	45[2]	6.5	48	1.20

[1] At full-scale water production of 20 mgd.
[2] Would be staged over 10 years.

Project 1 pump stations require 61 MW of power. This power demand and the annual pumping energy requirements exceed the amount of excess geothermal energy available in a 50-MW geothermal project. Therefore, a larger geothermal project would be required for Project 1 to be feasible. Power demand and energy requirements of Project 2 are well within the capacity of a 50-MW geothermal project.

Based on the comparison of costs and energy, Project 2 is much more feasible than Project 1. In addition, Project 1 has several major institutional and environmental constraints. It requires transfer of a large quantity of water from one region of the island to another. It requires more extensive construction and will have a significant impact on the flow of the Wailuku River. Project 1 also has much higher capital financing requirements and cannot be constructed in stages to match increasing water demands as is the case in Project 2.

Project 2 does have some possible constraints to its feasibility. Availability of the assumed water source, potable basal groundwater, needs to be verified by deeper test wells located farther inland along the west coast. Project 2 would also have some environmental impacts in construction and operation. However, these are much smaller than for Project 1. The availability and cost of excess geothermal energy also is uncertain at this time. This needs to be evaluated further for both Projects 1 and 2.

S.2 CONCLUSIONS

1. Future water needs exceed existing supplies on the dry side of the Big Island, especially in the Kona and South Kohala areas.

2. Potential water sources to meet the needs include surface waters from the windward side of the island and groundwater from both sides of the island.

3. The geothermal, hydroelectric, and pumped storage renewable energy technologies are most feasible for use in developing water resources on the island of Hawaii. Other potential technologies that may be feasible for use in water resources development include ocean thermal energy conversion, wind, solar thermal energy conversion, and biomass and municipal solid waste conversion.

4. It is technically feasible to integrate renewable energy development with water resources development on the Big Island. Twelve potential projects have been identified that would consist of various combinations of water sources, water needs, moving water, and moving energy.

5. Project 1, which consists of using renewable energy to move water over the saddle to supply leeward side water requirements is very expensive and has major institutional and environmental constraints.

6. Project 2, which consists of using renewable energy for deep well operation to supply water needs on the leeward side of the island appears to be quite feasible.

S.3 RECOMMENDATIONS

Several activities are recommended to further pursue the development of integrated water/renewable energy development on Hawaii.

1. Develop and evaluate two additional conceptual projects to compare to Project 2. These are (a) use of excess geothermal energy for desalination of brackish groundwater as in Alternatives E-3 and E-4, and (b) an extension of Project 2 to support groundwater development in the Keahole to Hookena area as in Alternative E-2.

2. Develop test wells to confirm the water quality, safe yield, and feasibility of installing and maintaining deep wells as proposed in Project 2.

3. Perform in-depth analysis in conjunction with HELCO and the geothermal developers to refine estimates of the timing and quantity of excess off-peak geothermal energy that may be available for water resources development on the Big Island.

4. Closely follow ongoing HECO studies of how Puna geothermal energy will be used on Oahu. Opportunities, methods, and benefits of supplying excess off-peak energy for water development should be incorporated into those studies.

5. Perform in-depth evaluations of how special energy costs rates might be allowed and negotiated for the use of excess off-peak geothermal energy.

CONTENTS

Section 1
INTRODUCTION

1.1 BACKGROUND

Hawaii currently imports most of its energy in the form of fuel oil. The State would like to be more self-sufficient in energy in order to control costs and reduce dependence on imports. The development and use of renewable energy resources on the islands has high potential for supplying much of Hawaii's future energy needs.

The State is also working to increase water supplies in water-short areas. The water is needed to support economic growth. As a result of the hydrologic conditions in the islands, rainfall and water supplies exceed needs in some areas, while in others, sometimes only a few miles away, water supplies are inadequate. Increasing water supplies in dry areas often means moving water from the wet areas. Transferring water and developing local supplies in dry areas often requires large amounts of energy.

Integrating the development of water and renewable energy resources may reduce the costs of both resources and improve feasibility. Interest in this potential is characterized by the adoption of a resolution by the Senate of the 13th Legislature of the State of Hawaii (Senate Resolution No. 187, S.D.1), which requested that both the Hawaii Department of Planning and Economic Development (DPED) and the Hawaii Department of Land and Natural Resources (DLNR) investigate the technical and economic feasibility of developing Hawaii's renewable energy resources in conjunction with the development of the State's water resources.

1.2 STUDY PURPOSE AND SCOPE

This study was commissioned by the DPED Energy Division in cooperation with the DLNR Division of Water and Land Development (DOWALD). The objective is to determine the economic and technical feasibility of combining renewable energy and water resource development in Hawaii. The study includes a general overview of various types of renewable energy in water resource development and a specific evaluation of using excess off-peak demand period geothermal energy for water resource development on the Island of Hawaii.

The scope of work consisted of the following general tasks:

1. An assessment of water resources needs

2. An assessment of how to develop water resources to meet those needs

3. An assessment of the potential use of renewable energy technologies

4. Identification of potential integrated water/ renewable energy projects

5. Development of conceptual plans and evaluation of two potential projects

This report contains separate sections presenting the results of each of the aforementioned tasks.

Section 2
ASSESSMENT OF WATER NEEDS AND AVAILABILITY

This section describes the current and projected water needs of the five hydrographic areas on the Big Island, along with a review of the availability of both surface water and groundwater that could be developed to meet those needs. It also describes, in less detail, the water resources and needs on Maui and Oahu. Those islands also have potential opportunities to integrate renewable energy projects with water resource development.

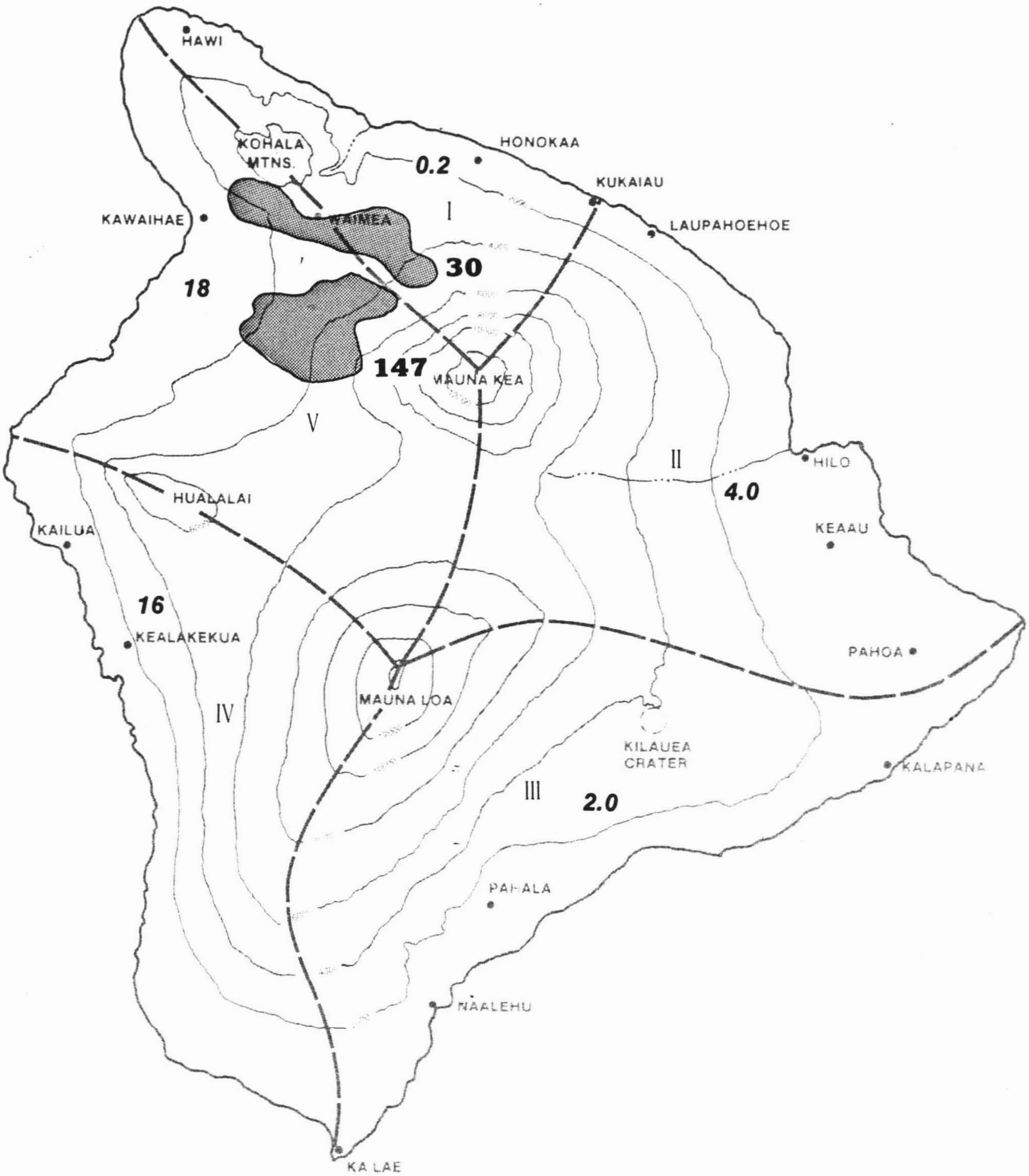
2.1 CURRENT WATER USE AND NEEDS

Water use and projected needs will be covered together in this section because they are closely intertwined. Knowing what is required in certain orders of magnitude while investigating available water from specific sources is of great help when studies are made to meet these needs. For the Island of Hawaii, water use and projected needs have been categorized by hydrographic areas or major drainage basins. Figure 2.1 shows the hydrographics areas and locations of water needs that are discussed in the following sections. For Maui and Oahu, the current water use and projected needs are reported in a generalized way for the island as a whole.

2.1.1 ISLAND OF HAWAII

The total current water use including both agricultural and domestic uses on the Island of Hawaii amounts to approximately 260 mgd. Table 2.1 shows the current water use of surface water and groundwater by hydrographic areas. Domestic water uses total approximately 17 mgd while agricultural uses amount to approximately 243 mgd for the Island of Hawaii. With regard to projected additional water needs, Table 2.2 summarizes the requirements by hydrographic areas.

The Department of Water Supply has prepared master plans to meet the projected municipal needs on the island. A series of improvements, including the development of groundwater sources, additional reservoir storage, and construction of water treatment facilities, is underway. New water sources must be developed in certain parts of the Big Island to meet anticipated increase in water demand. In addition, improvements to water mains are required to provide adequate distribution, water pressure, and delivered quantities of water. Major growth on the Island of Hawaii will be in Areas IV and V. In discussions between CH2M HILL and the Hawaii County Department of Water Supply and the Planning Department, significant growth is identified for resort



LEGEND

II HYDROGRAPHIC AREAS

ALISH Lands

16 ADDITIONAL DOMESTIC WATER NEEDS - 2000, MGD

30 POTENTIAL NEEDED AGRICULTURAL WATER, MGD

Figure 2.1
ADDITIONAL WATER NEEDS

CH2M HILL

Table 2.1
WATER USE BY HYDROGRAPHIC AREA
(million gallons per day)

Hydrographic Area	Ground Water Use	Surface Water Use
I	§1	52
II	93	97
III	5	2
IV	5	0
V	4	2
TOTALS	107	153

Table 2.2
ADDITIONAL WATER NEEDS
ON BIG ISLAND
(MGD)

Hydrographic Area	Domestic[1]	Agricultural[2]
I	0.2	30
II	4.0	--
III	2.0	--
IV	16	--
V	18	147
Totals	40.2	177

[1]Year 2000.

[2]Potential need for 26,500 acres of irrigable lands (ALISH Soil Classification Study).

properties in the North Kona and South Kona areas (Area IV and V). Various projections have been made for the additional water demands for the foreseeable future in the western parts of the Big Island and these projections form the basis for the figures in Table 2.2. The following is an area-by-area discussion for the Island of Hawaii.

2.1.1.1 Area I

Area I covers the area from Upolu Point to Ookala in the northern part of the Big Island. This area currently uses about 1.8 mgd and the projected additional domestic water demands are estimated to be about 0.2 mgd--mostly in the Waimea Parker Ranch saddle.

2.1.1.2 Area II

The Hilo area is situated in Area II. This urban city's population accounts for the area's relatively high existing domestic water use of 10.7 mgd. Projected additional water demands in this area amount to 4.0 mgd.

2.1.1.3 Area III

Area III covers the southeastern portion of the island from Kapoho to South Point. Domestic water use is minimal at 1.3 mgd and projected additional domestic use in this area is estimated to be about 2.0 mgd, which includes development needs at South Point, Hawaiian Homes Lands, and increased activity at Punaluu.

2.1.1.4 Area IV

This area is known as the Kona region, a rapidly growing area, with increased activity in the last decade. Many resort hotels and condominiums have been constructed and more are planned. The availability of water is key to the rate of growth in this area. The area currently uses about 4 mgd of domestic water and little agricultural irrigation takes place in this region. Discussions between CH2M HILL and the Hawaii County Department of Water Supply and the Planning Department indicate that significant growth will be experienced in the Kona area and it is estimated that another 16 mgd of domestic water will be required for hydrographic Area IV.

2.1.1.5 Area V

Area V represents an interesting growth area. Long range planning initially called for constructing the Queen's Highway from Kailua-Kona to Kawaihae a few years ago. This highway across vacant lands has opened up new opportunities for resort development along the coast. In the mauka or mountain reaches of Area V, the U.S. Department of Army plans to increase the training activities at Pohakuloa. The County Department of Planning has compiled the many requests for general plan and zoning amendments and from this list has projected a water need of about 18 mgd for Area V.

In discussions between CH2M HILL and the Hawaii County Department of Water Supply and Planning Department, significant additional growth not reflected in previous studies is identified for resort properties in the Kona and South Kohala areas. Various projections have been made for the additional water demands in the next 20 years in these western areas of the Big Island. The Department of Water Supply is projecting an additional population of 30,000-35,000 in the area extending south from Mahukona to the Mauna Lani Resort. Total water demand is projected to be 18 mgd. The Planning Department has considered these developments as well as those to the south in the Kona area. Approximately 17,300 resort units have been approved to be built during the the next 20 years and an additional 11,100 resort units are under consideration. Including a factor for supporting employment and housing needs, these figures indicate a total potable water demand in this area of 34.3 mgd.

The existing County of Hawaii potable water system extends from Kawaihae to the Mauna Lani Resort with the area south to the Kona Airport being served by private facilities. Current capacity will be unable to meet projected needs.

Additional resort development will, therefore, require significant new water supply and distribution systems along the Kona Coast in the near future. Potential water resources available to supply this area include the basal aquifers near Hawi and along the northewast coast between Honokaa and Kapoho. Limited supplies could be drawn from the thin basal aquifer along the Kona coastline below elevation 1,200 feet but because of the relatively low potential of this aquifer (fresh water levels stand 4 to 4.5 feet above mean sea level) they cannot be considered for meeting the planned levels of demand.

2.1.1.6 Additional Irrigation Water Needs

The current irrigation water use on the Big Island is about 110 mgd (Hawaii Department of Agriculture, 1985). The Department of Agriculture, in the State Agriculture Functional Plan, Technical Reference Document, has projected future additional irrigation water needs to be approximately 177 mgd. This is based on providing an average of 6,700 gallons/acre/day (7.5 ac-ft/ac) to 26,500 acres of irrigable land. This irrigable land includes ALISH (Agricultural Lands of Importance in the State of Hawaii) lands near

Waimea classified as prime if irrigated. Figure 2.1 indicates the location of these ALISH classified lands. Area I has a need for about 30 mgd and Area V has a need for about 147 mgd of additional irrigation water.

2.1.2 MAUI

With one of the nation's largest sugar cane plantations--Hawaiian Commercial and Sugar--located on this island, the current water use picture of the Island of Maui is dominated by the large amounts of water used to irrigate sugar cane. Total agricultural use of water is about 591 mgd and the total current use of domestic water is approximately 21 mgd. Additional Maui water requirements for the future include domestic water needs in the Makena-Kihei region, the West Maui area from Kaanapali to Honokohua, and the Kahului-Wailuku district. Regarding the integration of renewable energy sources with the energy needs of developing additional waters, this study shows that there is a definite need for additional waters on Maui and that the new sources are available. Economical power availability will accelerate water and economic development.

2.1.3 OAHU

Most of the people in Hawaii live on the Island of Oahu, which accounts for the large current average domestic water use of 135 mgd. The two sugar cane plantations on Oahu, along with diversified farming, currently use about 246 mgd of agricultural water. Between 1987 and the turn of the century, there will be a definite need for additional water development on Oahu. New developments such as West Beach, Mililani Town mauka of the H-2 Freeway, Lear Sigler's AMFAC lands on Bishop Estate property, and growth in the City of Honolulu, all require large amounts of new water. By the year 2000, it is estimated that an additional 77 mgd will be needed and another 89 mgd by 2020. Geothermal power transmitted through a cable from the Big Island will definitely enhance the water development program, since all new waters developed from the basal lens require power to lift the water several hundred feet. When Oahu develops alternative water sources such as desalting brackish coastal groundwater, the availability of renewable energy sources will be a key economic feasibility factor.

2.2 AVAILABILITY OF WATER RESOURCES TO MEET NEEDS

2.2.1 ISLAND OF HAWAII

The Big Island receives a daily average rainfall of 14,100 million gallons. Between the 2,000 and 4,000-foot elevations on the windward side of the island, the rainfall is high. It reaches 300 inches near Hilo, which is known as the wettest city in the world. On the other hand, rainfall is sparse on the leeward, west side of the island with less than 10 inches average per year recorded in the Kawaihae area. Figure 2.2 shows the rainfall distribution on the Big Island.

Evapotranspiration has been estimated to be about 44 percent for this island and stream flow runoff to the ocean measures about 25 percent. The remaining amount (31 percent) percolates into the ground to the basal aquifer.

2.2.1.1 Surface Waters--Island of Hawaii

Surface water availability depends on rainfall and is influenced by the geology of the area. As shown in Table 2.3, hydrographic Area II has the greatest amount of surface flows while hydrographic Areas IV and V exhibit the smallest amount of surface water discharge. Compared with the projected water needs, the figures in Table 2.3 indicate that surface flows can probably be developed from Areas I and II for use in West Hawaii if economical power is available for pumping costs. Surface waters have been extensively developed (78 mgd) from the northeast slopes of the Kohala Mountains, primarily for agricultural use. The number of perennial streams on the Big Island is limited to the reaches along the Hamakua and North Kohala coasts. This is indicative of the Kohala mountain being the oldest geological area on the Big Island with relatively impervious weathered surfaces. The highly pervious nature of the Mauna Loa and Mauna Kea mountains is due to their relatively recent volcanic activity. This pervious surface rock allows for rain waters to percolate through and streams become intermittent rather than perennial. Some streams flow perennially in their wet upper reaches but lose their water to the groundwater system before they reach the sea. Table 2.3 shows the distribution of stream runoff by hydrographic area.

2.2.1.2 Groundwaters--Island of Hawaii

Groundwater occurs as basal water near sea levels and at higher elevations as dike-impounded water and as perched water. Figure 2.3 illustrates the geographic distribution of the various types of groundwater on the island of Hawaii.

The absence of a caprock and the high permeability of the lavas along the coastline causes the basal water to stand nearly at sea level. Heavy rainfall on the windward side of the Kohala Mountains contributes a considerable amount of recharge to the basal-water body. Basal springs with flows of about 1 mgd are common between Niulii and Kukuihale. The total discharge of basal water in the northeast quadrant of the island is approximately 250 mgd or a flux of 20 mgd per

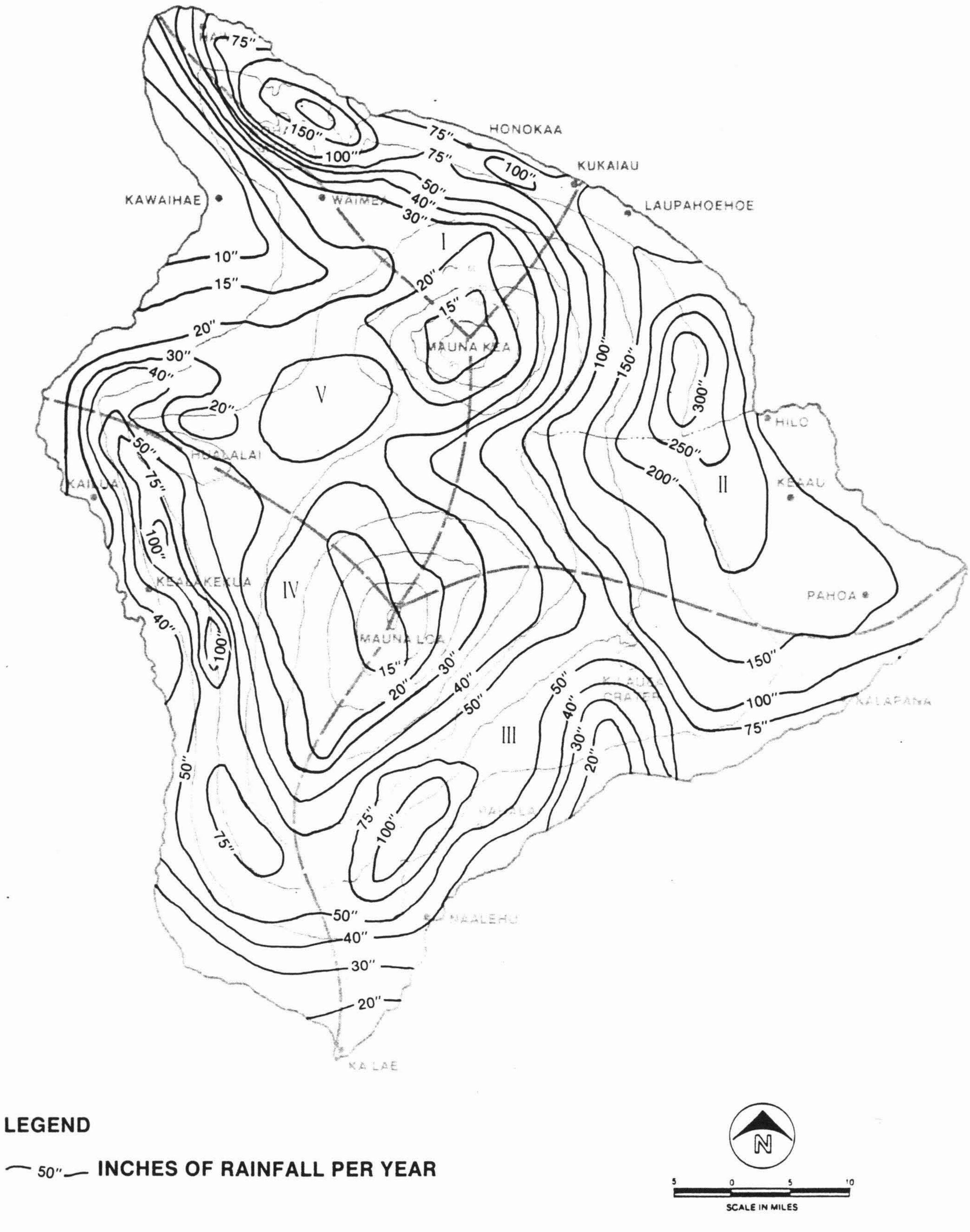
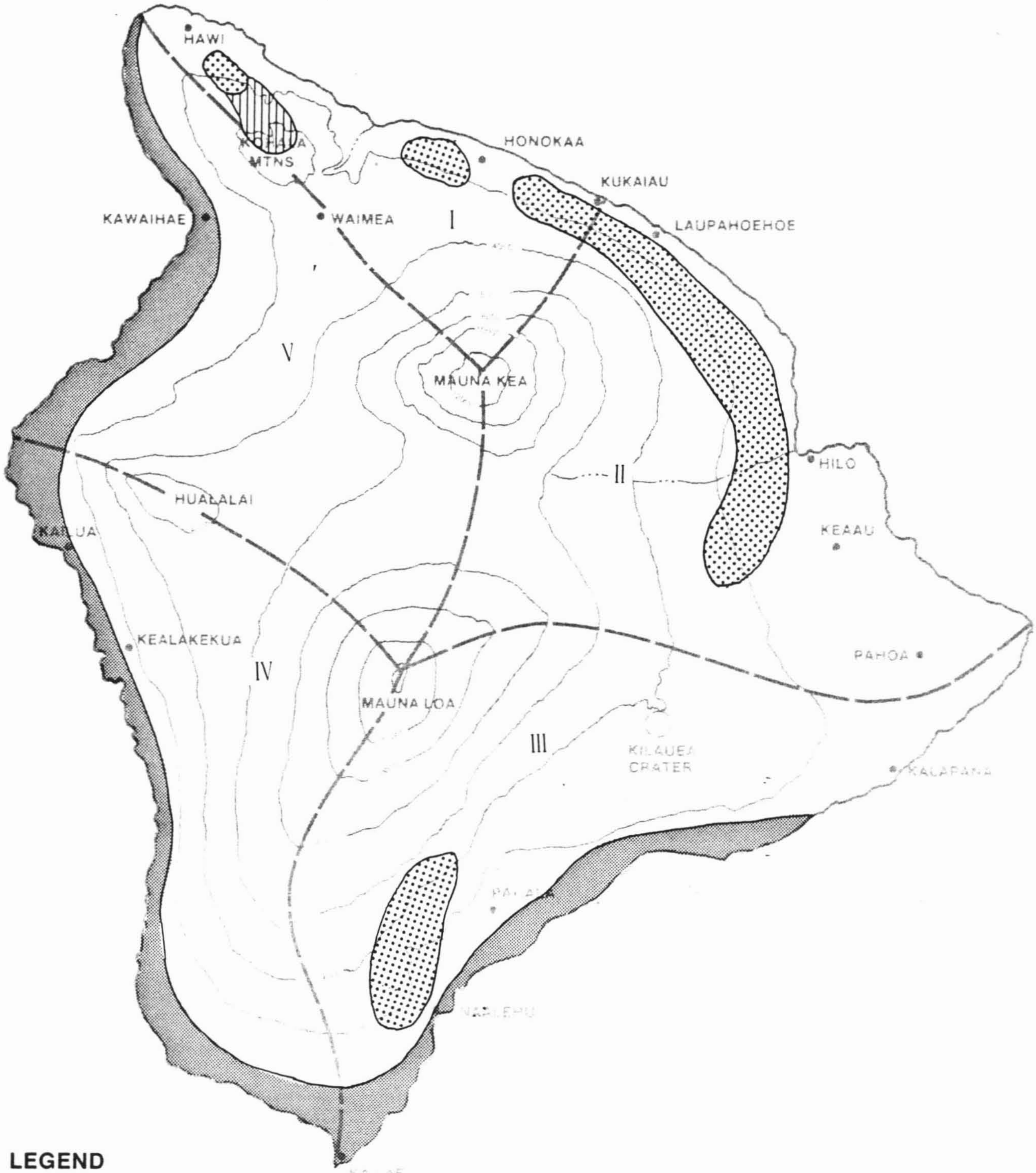


Figure 2.2
RAINFALL DISTRIBUTION

Table 2.3
WATER SOURCE AVAILABILITY--ISLAND OF HAWAII
(MGD)

Hydrographic Area	Rainfall	Discharged as Surface Water	Recharged to Ground Water	Comments
I	1,430	430	305	Surface and Ground Water Available
II	7,335	2,510	3,095	Large Amounts of Surface and Ground Water Available
III	2,340	235	400	Area is Remote to West Hawaii
IV	1,790	180	345	Ground Water Availability - 4 MGD/mi in Drier Areas, 10 MGD in Wet Areas
V	1,160	180	235	Water is Needed for Development in This Area



LEGEND

- BRACKISH BASAL WATER
- BASAL WATER FLOATING ON SALT WATER
- WATER CONFINED BY DIKES AND NOT FLOATING ON SALT WATER
- WATER PERCHED ON ASH, WEATHERED SOIL OR ALLUVIUM

Figure 2.3
GROUNDWATER MAP

CH2M HILL

mile of shoreline. This flux increases to nearly 40 mgd per mile in the coastline to the east of Mauna Kea between Hilo and Laupahoehoe. Basal water of variable quality underlies all the south Hilo area, except possibly where dikes may impound water in rift zones. The visible discharge of basal water in this area is 300 to 400 mgd with a significant additional amount discharging as diffused flow below sea level. The basal water discharge between Cape Kumukahi and Hilo is approximately 100 mgd per shoreline mile.

The unused basal water flow to the ocean between Hilo and Laupahoehoe probably represents the largest unused source of groundwater in the State of Hawaii. The best potential for developing large supplies of basal water in this southeast quadrant is in the south Hilo area. Because of the large quantities of groundwater moving towards the coast, there will be relatively little risk of significant increases in salinity if pumpage is increased in this area.

Large supplies of fresh groundwater are available in the coastal area between Punaluu and Honuapo, as evidenced by the Ninole and Kawaa Springs. These springs have been estimated to discharge 29 and 13 mgd, respectively. These springs lie along the Honuapo-Kaoiki fault, which probably intercepts much of the flow from Mauna Loa. To the southwest of Honuapo the groundwater flux is only 2 mgd per mile and any wells located in this area should be as far inland as possible to limit salinity problems. Some high-level impounded water near Pahala has been tapped by a shaft and represents a potentially large source of water.

The south Kona District between South Point and north of Kailua lies on the leeward side of the island and, therefore, receives little orographic tradewind rainfall. Most of the rainfall comes from convective rainshowers on the slopes of Hualalai and Mauna Loa. Basal groundwater most likely underlies the area except in the rift zones. The shoreline discharge of basal water is expected to be about 4 mgd per mile in dry areas and up to 10 mgd per mile in wet areas such as along the west slopes of Hualalai and Mauna Loa. All basal water is mixed with sea water along the coast because of the highly permeable nature of the aquifers. This mixing of fresh and saline waters has occurred up to 3 miles inland with a minimum depth to fresh water in those areas being in excess of 1,000 feet.

The area from Puako Bay north to Upolu Point lies in the driest part of the island. Considerable recharge along Kohala Mountain moves down into the basal-water body but because of mixing along the coast, it is expected that water having a chloride content of less than 200-300 mg/L cannot be found closer than 3 or 4 miles from the coast. Most of the groundwater in the Kawaihae area is highly saline near the coast and is unsuitable for domestic consumption without treatment. A significant basal water body below Waikoloa Village could hold some promise.

2.2.2 MAUI

The Island of Maui receives an average of 80 inches of rainfall per year (2,840 million gallons per day) with about 75 percent of that rainfall occurring on Haleakala or East Maui. Two thirds of this rain falls on the lower windward slopes on the northeast side of the island. Large quantities of surface water are transported from this area through diversion systems for use on sugar cane fields in the drier areas around Puunene.

2.2.2.1 Surface Waters--Maui

Perennial streams occur in the wet areas of West Maui and in most areas of East Maui. At the present time, large quantities of surface waters are transported through diversion systems from the wet areas for use on arable lands. Undeveloped surface waters are mostly located in remote areas of Maui and with economical sources of power available these sources may be developed. Also, power availability at low cost will make some lower reaches of surface water available for use by pumping to areas of need.

2.2.2.2 Groundwaters--Maui

Groundwater development has been occurring for more than a century on the Island of Maui. Additional groundwater is available in the remote areas of West Maui in the region adjacent to Honokohau Valley. Also, in the northwest area of Maui, the Kohakuloa area beyond Waihee has a potential for more groundwater development, particularly if economical power were available. The other potential groundwater source not yet fully developed on Maui is the East Maui region on the lower slopes of the northern flanks of Haleakala (EMI Ditch area).

2.2.3 OAHU

The average rainfall on Oahu is about 65 inches per year (1,800 mgd) with most of that rain falling on the Koolau Range. The municipal, industrial, and agricultural water demands are expected to approach the average year potential supply of the island in the year 2000. The Oahu Water Plan estimates that the available water quantity on Oahu could be developed to its limits by the turn of the century. This estimate assumes that uses will be maintained under existing conditions.

2.2.3.1 Surface Waters--Oahu

Windward Oahu, from Maunawili to Kahuku shows an occurrence of perennial streams. Some of these streams sustain their low flows through leakage from high-level dike compartments and seeps. In some sections of the leeward slopes of the Koolau Range, some streams are perennial in their headwaters, fed by persistent daily rainfall. However, flow to the sea is intermittent because of diversions to sugar cane fields or because some waters seep into the ground in certain areas. Because of the steep slopes and the porous nature of the ground, in-stream impounding reservoirs are not feasible on the Island of Oahu and very little additional, if any, surface water development is anticipated.

2.2.3.2 Groundwaters-Oahu

Groundwater on Oahu occurs as basal, as dike-confined, and as perched water. Domestic water is principally developed from groundwater and very little treatment has been necessary in the past. In recent years, groundwater has been treated with granular activated carbon treatment plants and with air stripping installations to remove trace organic contaminants. About 420 mgd of groundwater has been developed on Oahu and it is expected that less than one-fifth of that amount might be developed for future use. Since all water development on Oahu will require pumping from the ground, economical power sources available to Oahu will help to expedite the required water development.

Table 2.3
WATER SOURCE AVAILABILITY--ISLAND OF HAWAII
(mgd)

Hydrographic Area	Rainfall	Discharged as Surface Water	Recharged to Groundwater	Comments
I	1,430	430	305	Surface and Groundwater Available
II	7,335	2,510	3,095	Large Amounts of Surface and Ground-Water Available
III	2,340	235	400	Area is Remote to West Hawaii
IV	1,790	180	345	Groundwater Availability - 4 mgd/mi in Drier Areas, 10 mgd in Wet Areas
V	1,160	180	235	Water is Needed for Development in This Area

Section 3
DESCRIPTION OF MEANS TO DEVELOP WATER RESOURCES

The ability to develop water resources to meet the needs of the Island of Hawaii by integrating water and renewable energy sources is described in this section. As indicated in Section 2, the additional needs in the next few years appear to be concentrated mostly in hydrographic Areas IV and V. The development of water for use in these areas will enable the County of Hawaii to proceed with their economic development plans.

3.1 POTENTIAL SOURCES OF WATER--ISLAND OF HAWAII

With the realization that the main service area for this type of water/energy project will be in Areas IV and V, specific water projects from surface water and groundwater areas have been schematically developed. The locations of the potential water sources are shown in Figure 3.1 and are described in the following sections. The potential water resources are listed and their potential for use in an integrated water/energy project is summarized in Table 3.1.

3.1.1 SURFACE WATER SCHEMES--ISLAND OF HAWAII

3.1.1.1 Wailuku River

The upper reaches of the Wailuku River above Hilo have been envisioned as a source of water for service areas mauka of its headwaters for many years. The Federal Department of the Army has wanted to enlarge its training facilities in the Pohakuloa area of the saddle between Mauna Loa and Mauna Kea mountains but has been unable to do so because of a lack of water.

With regard to the range of water available from the Wailuku River, the Hawaii water resources regional study reported that 183 mgd is available with proper storage. Figure 3.2 shows flow characteristics of the Wailuku River, including a duration-discharge curve and mean discharge of this river. This is a very good source of water for the water/energy integration project and hydropower can be generated if the water is distributed to the lower areas of hydrographic Areas IV and V.

3.1.1.2 Hamakua Coast

Between Waipio and Hilo there are many perennial streams that currently flow undeveloped to the ocean. The total runoff, as shown in Table 2.3, is over 2,000 mgd. This is a source that possibly could be tapped. With low cost power, streamflows from these rivers could be pumped over the

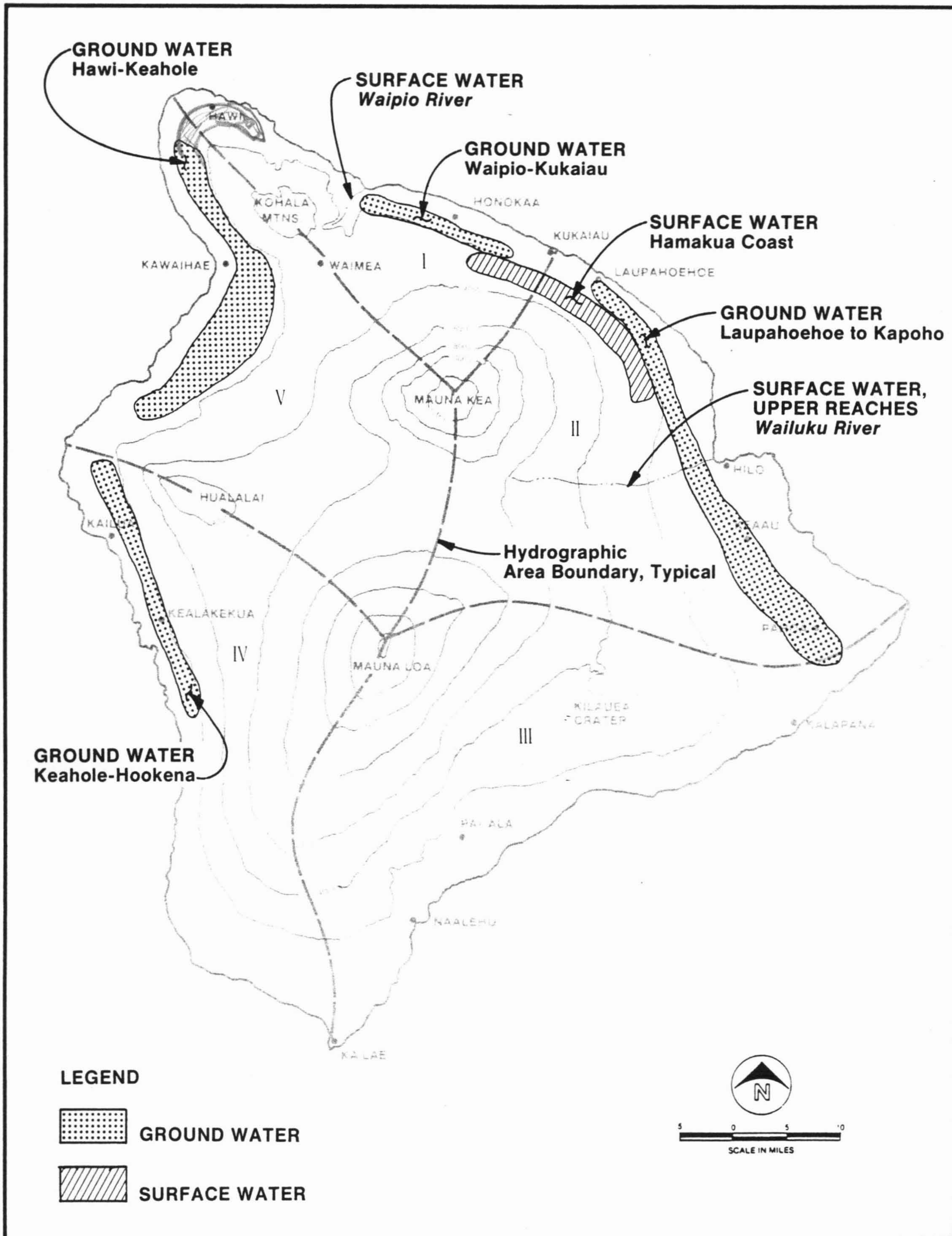
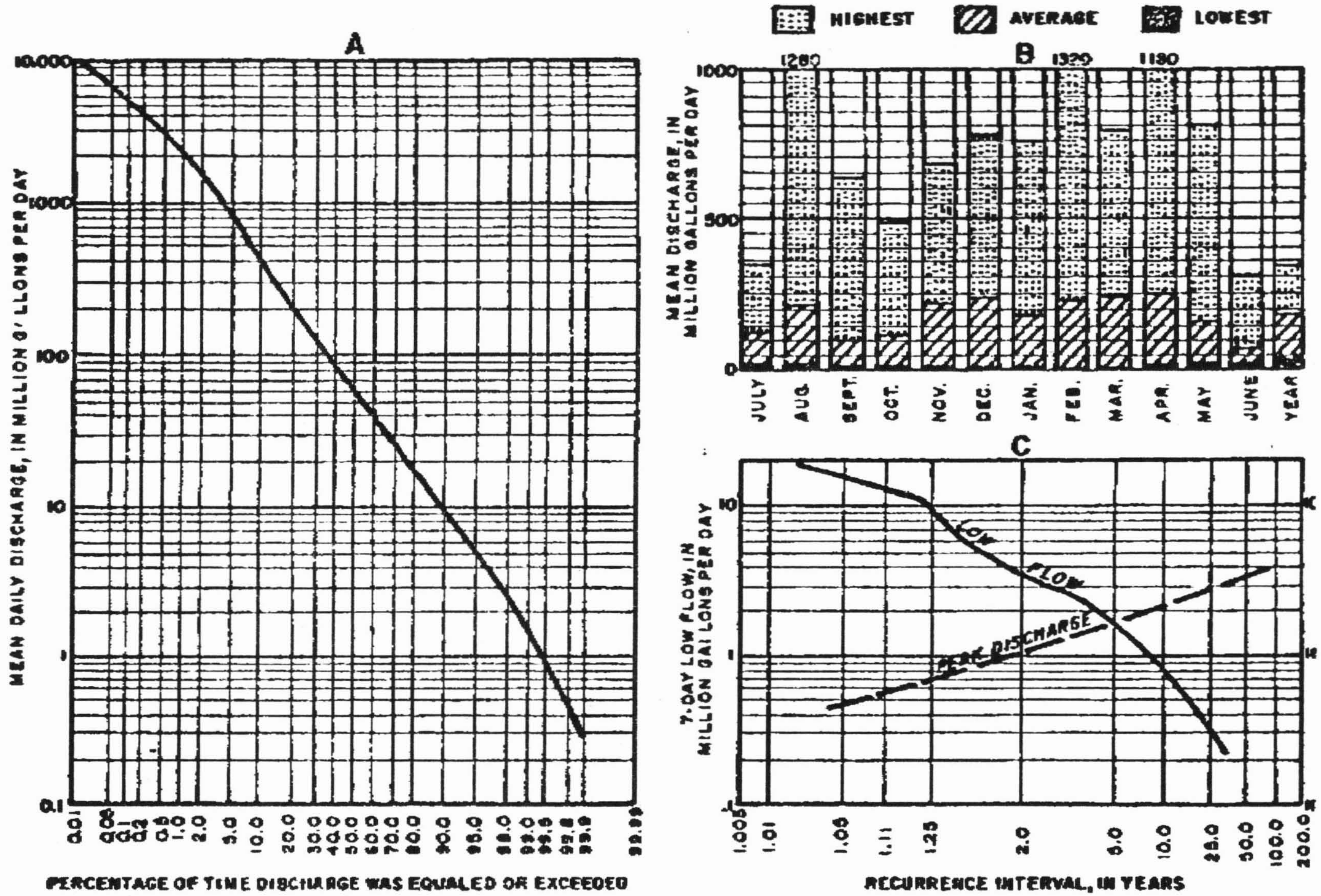


Figure 3.1
POTENTIAL WATER SOURCES

Table 3.1
POTENTIAL WATER SOURCES--ISLAND OF HAWAII

Source	Hydrographic Area	Rate of Water Availability	Source Potential for Water/ Energy Project	Comments
Surface Waters Wailuku River (Upper Reaches)	II	183 mgd[a]	Good	Very good source of water for water/ energy project after lifting water through saddle area. Stream flow varies through certain reaches.
Hamakua Coast	I & II	Total runoff = 2940 mgd	Fair	Abundance of surface water, relatively long distance to West Hawaii.
Waipio River	I	--	Fair	Remote source - high initial and operational costs.
Groundwaters (Basal) Hawi - Keahole o Potable +1200' el. (Varies) o Brackish - Below 1200' el.	V	2 mgd/mi	Very Good	Hawi-Kawaihae, groundwater available for development.
Waipio Valley - Kukaiau o Potable below 1000' el.	I	2 - 5 mgd/mi	Fair	Groundwater from this area considered for use Waimea - Honokaa.
Keahole - Hookena o Potable above 1000' el.	IV	4 - 5 mgd/mi	Good	Groundwater from this area scheduled for use in North Kona District.
Laupahoehoe - Kapoho o Potable above 500' el.	II	10 mgd/mi	Fair	Adequate groundwater, remote from West Hawaii.

Source: Surface and Groundwater Resources, Hawaii Water Resources Regional Study, p. 78.



Station No. 7040.00, Altitude 1,070 ft., Drainage Area 125 sq. mi., Period Used 1930-40, 1942-69, Max. Discharge 41,000 mgd, Min. Discharge 0.16, Mean Discharge 181 mgd.

Figure 3.2
FLOW CHARACTERISTICS OF WAILUKU RIVER AT PIIHONUA

Waimea saddle and used in the service areas of West Hawaii. The distances from these sources to service areas are, however, very long.

3.1.1.3 Waipio River

Large quantities of river water amounting to several hundred million gallons per day currently flow to the ocean untapped from the Waipio River. This is a remote surface source requiring high pumping lifts to reach service areas. The Waipio River resource has been the subject of several studies but the remoteness of this source has made it infeasible to develop to date.

3.1.2 GROUNDWATER SCHEMES--ISLAND OF HAWAII

All groundwater developments in this study consider taking water from the basal aquifers of the Island of Hawaii. Again, economical low cost power to pump these groundwaters to the surface for use will expedite groundwater development.

3.1.2.1 Basal Water--Hawi to Keahole

Because of the great demand for resort development in hydrographic Area V, exploratory well drilling has taken place in the lower reaches of the service area. These wells have shown that potable water cannot be developed unless the well is located about 3 or 4 miles back from the sea coast. Wells at elevation 1,200 feet have been successful in locating potable basal sources. All of the wells below this elevation in Area V have been brackish. The amount of groundwater that can be developed in this area is generally assumed to be only about 2 mgd per mile because of the dryness of the area. There are, however, as many as 40 miles of coastline in the area and wells spaced adequately would enable meaningful groundwater development. If brackish waters are to be used with desalinization plants, there is an abundance of brackish water in this area. Since the further a brackish water well is located away from the ocean, the better the quality of water, brackish water wells used for desalinization plants should probably be placed about 1 or 2 miles from the coast. The development of basal waters in West Hawaii will allow for incremental water development because the wells can be located adjacent to the areas of need and can be installed in stages.

3.1.2.2 Basal Water-Waipio to Kukaiau

This is a heavy rainfall area resulting in a thick basal water lens. Potable water can be developed in the lower reaches at elevations 700 feet and above. It is estimated that the groundwater that can be developed in this region varies from 2 to 5 mgd per mile. This area, however, has been considered for use in Waimea because that area has experienced shortages of water in the past. The scheme to use this basal source would be to transfer water through the Waimea region to West Hawaii.

3.1.2.3 Kona Basal Water-Keahole to Hookena

Groundwater development has occurred in this area since the 1960s. The area from Keahole to Hookena in South Kona has a thin basal groundwater aquifer with water levels only 2 or 3 feet above sea level. Because of the high permeability of the lavas of the region, wells in this area experience minimal drawdown (a few tenths of a foot) when pumped up to 1 mgd. The aquifer, therefore, serves as the source of water for the area from Keahole to Hookena. The needs of 16 mgd of hydrographic Area IV can probably be satisfied by developing water from this aquifer. Any low cost energy available to the Kona area will certainly help keep costs to a minimum.

3.1.2.4 Basal Waters of Hydrographic Area II--Laupahoehoe to Kapoho

Potable groundwaters can be developed in this area at low ground elevations. In some areas drinking water can be obtained from wells at elevation 500 feet. There is an abundance of groundwater in this area with the estimated flux in the neighborhood of 10 mgd per mile. This source is, however, very remote from the service areas of West Hawaii.

3.2 INSTITUTIONAL AND ENVIRONMENTAL CONSIDERATIONS

The water development schemes that have been considered as potential sources of water to meet the future needs of the Island of Hawaii will be discussed in this section from the institutional and environmental viewpoint.

3.2.1 SURFACE WATERS

Whenever stream waters are diverted from their natural courses in the State of Hawaii, an environmental impact statement (EIS) is prepared. This EIS examines social, economic, and environmental effects of diverting stream waters for domestic, agricultural, or industrial purposes. The EIS process includes public hearings and affords all interested parties an opportunity to submit written comments concerning the findings of the EIS. All submitted comments require a response before the EIS can be considered for acceptance. Requirements of the preparation of an EIS also include descriptions of alternatives to the proposal of diverting stream water for use in service areas. Before a project can be initiated, the EIS must be accepted by the appropriate agency. The EIS process, therefore, is a means by which specific projects are analyzed completely for social, economic, and environmental impacts. In this way, all institutional as well as environmental considerations are fully investigated and discussed by the community affected before the project can proceed.

When diverted streams are located in a State land use conservation district, approval must be received from the State Board of Land and Natural Resources before the project can proceed. The State Department of Health's approval must be obtained when the water is to be diverted for domestic purposes.

3.2.2 GROUNDWATERS

Environmental impact statements are also prepared for the withdrawal of groundwaters from aquifers. These EISs investigate the withdrawal of certain quantities of water from specific aquifers and report the effect on the water resource. They also look into the physical disturbance of land areas and related environmental concerns. The social impacts of new developments resulting from increased groundwater development are also fully investigated. Groundwater development does not generally have an adverse impact on the environment. Construction inconveniences are temporary and can be readily mitigated. Permanent facilities above ground, such as pumps, control buildings, and tanks, can be made to be aesthetically acceptable.

With regard to institutional concerns of groundwater development, on Oahu approval for withdrawal of new waters must receive governmental approval. On the Island of Hawaii, however, no controls, other than notifying agencies of the location, amount, and use of the water, currently exist. The Department of Health has recently instituted an underground injection control program for the State, which requires an approval of the construction of all injection wells. All water facilities' installations must also receive appropriate government approvals.

Where groundwater activities take place in conservation lands, approvals from the Board of Land and Natural Resources must be received before the project can be initiated.

Section 4
RENEWABLE ENERGY RESOURCES ASSESSMENT

This chapter presents an assessment of the renewable electric energy resources that could be used on the islands in conjunction with water resources development. Several renewable energy technologies are briefly described and their feasibility for use in developing water resources is evaluated. The energy resources framework for development of an integrated water/energy project using Big Island geothermal power is presented and the energy available for water resources development is quantified.

4.1 RENEWABLE ENERGY TECHNOLOGIES

Considerable work has been done to evaluate the feasibility of various renewable energy technologies in the State of Hawaii. The evaluations have included pilot testing, and in some instances, large-scale implementation. The Hawaii Integrated Energy Assessment (DPED and Lawrence Berkeley Laboratory, 1981) identified the following technologies that can rely on resources indigenous to Hawaii and that are currently in use or are expected to be ready for large-scale commercial use by 2005:

- Geothermal
- Ocean thermal energy conversion (OTEC)
- Wind
- Solar, via thermal energy conversion (STEC) and photovoltaics
- Hydroelectric and pumped storage
- Biomass and municipal solid waste conversion

Table 4.1 discusses each of the technologies that have been evaluated and includes information on their potential locations on the islands, the potential magnitude of power production, projected online dates, relative capital costs, and suitability for load serving.

Of the renewable energy resources that have been evaluated, geothermal has been identified as having a large potential for development on the Island of Hawaii. However, the larger load centers in the islands are not on the Island of Hawaii; they are on Oahu and Maui. As a result, the Hawaiian Deep Water Cable (HDWC) is being considered to transmit geothermal-based energy to Maui and Oahu. This project is discussed in more detail later in this report. Even with the cable, it appears that there will be energy available from geothermal development that will be surplus to existing and projected loads because of the diurnal pattern of the loads. During off-peak hours, there will be surplus generating capacity that could be used to support new energy consuming loads, such as water resources development, that could take advantage of these off-peak surpluses. At various times, there may also be surplus capacity available during peak load periods.

OTEC, wind, STEC, photovoltaics, hydroelectric, and pumped storage are potential technologies on all of the major islands. Biomass conversion is used now, predominantly in the sugarcane growing and processing areas. The larger cities are potential sites for municipal solid waste conversion.

Potential geothermal energy production has been estimated to be 1,000 MW on the Big Island. OTEC potential has been estimated at 440 MW in each of the counties. The wind and STEC resource bases exceed limits of practical application because of concern for reliability. However, wind energy production could provide up to 20 percent of the load for each county. STEC potential has been estimated to be 440 MW for each county. Potential photovoltaic energy production has been estimated to be 116 MW for each county. Hydroelectric and pumped storage production potentials have been estimated at 100 MW for all four counties combined. Biomass conversion potential has been estimated to be 164 MW for all four counties, and municipal solid waste potential is 40 MW on Oahu.

A small amount of geothermal energy is being used now on the Big Island. Expansion to a total of about 550 MW in the next 25 years has been considered. OTEC technology is being pilot tested and is expected to be feasible between 1995 and 2005. Sizable wind, hydroelectric, and biomass conversion projects currently exist on the islands. STEC, photovoltaic, and pumped storage projects are technically proven, but require site and economic conditions suitable for implementation. A 40-MW municipal solid waste conversion project is currently being developed on Oahu.

The relative capital costs of the various renewable energy technologies are presented in Table 4.1. The current cost of developing geothermal energy has been estimated to be \$3,000/kW. This may decrease to \$1,200/kW in 25 years. OTEC is expected to be somewhat more expensive, costing about \$8,000/kW in the near future. Wind generation development costs are reportedly about \$2,500/kW now and are expected to reduce to \$700/kW as commercial use continues to expand. STEC capital costs will range from \$3,000 to \$2,000/kW. Photovoltaic conversion of solar energy is the most expensive of the renewable energy technologies considered. Major technical improvements are needed to reduce its capital costs to a level reasonable for large electrical energy production capacity. Hydroelectric and pumped storage capital costs may average \$2,000/kW, but can vary

Table 4.1
RENEWABLE ENERGY TECHNOLOGIES FOR ELECTRICAL POWER GENERATION[1]

Technology	Locations	Maximum Resource Potential in 2005	On-Line Dates	Relative Capital Costs	Load Suitability
Geothermal	Kilauea east rift zone on Hawaii is a large proven resource. Several other potentially feasible sites have been identified on Hawaii and on Maui and Oahu.	Puna area on Hawaii has potential for development of 1,000 MW. The other areas have not been studied to as great an extent and do not have estimates of potential power development.	Puna geothermal area: Current capacity is 3 MW 1989 add 12.5 MW for Hawaii 1993 add 12.5 MW for Hawaii 1995 add 200 MW for Oahu 1997 add 300 MW for Oahu	\$3,000 to \$1,200/kW[2] of installed capacity	Base load
OTEC	Potential coastal sites include from Keahale Point to Hilo on the southern portions of Hawaii, southern Kahoolawe, eastern Maui, Kalaupapa Peninsula on Molokai, Kaena Point to Kahae Point and the eastern end of Oahu, and Kilauea Point and southern Kauai.	440 MW in each county.	1995 to 2005	\$8,000 to \$2,600/kW[2]	Base load
Wind	South Point, North Kohala, and coastal portions of Puna area on Hawaii. Southeast coast, central valley, and northwest coast on Maui. Southeast coast and northwest coast of Molokai. West end, Kolokole Pass, Kahuku, and Kaena Point on Oahu. Southeast coast and northwest coasts on Kauai.	Resource base exceeds practical application. Limited to 20% of installed generating capacity. 432 MW on Oahu by 2005.	Major facilities now installed.	\$2,500 to \$700/kW[2]	Base, intermittent, or peak loads
STEC	Kaupulehu and Kaniku lava flows and undissected uplands on Hualalai and Mauna Loa on Hawaii. Makua Valley on Oahu. Upland slopes of Puu Nana and the Mahana Saddle near Kepuki and the region near Mauna Loa on Molokai. South-central Lanai, Palawai basin and Mauna Lei Valley on Lanai. Western Maui coast and central Maui near Wailuku on Maui. Kilohana upland slopes, Lihue basin, and Lihue plain on Kauai.	Resource base far exceeds practical application. 440 MW in each county.	Technology is currently available, but installation limited by site availability and economics.	\$3,000 to \$2,000/kW[2]	Intermittent load
Solar, Photovoltaics	Similar to those described for STEC.	116 MW for each county.	Technology is available but costly.	\$18,000 to \$2,600/kW[2]	Intermittent load
Hydroelectric	Major projects currently exist on Hawaii, Kauai, and Maui. Other prospective sites are on Oahu and Molokai.	100 MW for all four counties.	Major facilities are currently in operation with planning continuing on additional sites.	\$2,000/kW	Base, intermittent, or peak loads
Pumped Storage	Potential sites have been identified on Kauai, Oahu, Molokai, Maui, and Hawaii.	100 MW for all four counties.	Sites have been identified and await feasible economic and other conditions for development.	\$2,000/kW	Peak loads
Biomass and MSW Conversion	Sugarcane and pineapple growing areas for use of bagasse and larger cities for use of municipal refuse.	Biomass--164 MW for all four counties. Municipal solid waste--40 MW on Oahu.	Currently in widespread operation for bagasse burning.	\$1,200 to \$2,200/kW	Base, intermittent, or peak loads

Notes:
[1]Source, updated and modified from a similar table in DPED and Lawrence Berkeley Laboratory, 1981.
[2]1980 dollars; declining ranges indicate a decline in costs as commercialization takes place.

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significantly depending on site conditions. The capital cost of biomass and municipal solid waste conversion has been estimated to be $1,200 to $2,200/kW.

The geothermal and OTEC technologies are most suitable for providing base power supplies. They are best operated continuously at high capacity and are expected to have low annual cost. The wind, hydroelectric, and biomass and municipal solid waste conversion technologies can, within limits, be operated to supply base, intermittent, or peak demands. The solar technologies, STEC and photovoltaics, would supply intermittent power during periods of sunshine. Pumped storage facilities are normally developed to convert base power supplies for meeting peak demands.

In many cases, the output of the energy resource needs to be reshaped or supplemented in order to serve the load patterns. As an example, wind generation is not always available and must, therefore, be backed up by a dependable form of generation in order to reliably serve loads.

4.2 CONSIDERATIONS FOR RENEWABLE ENERGY RESOURCES DEVELOPMENT FOR USE IN WATER RESOURCES DEVELOPMENT

Several factors related to power supply must be considered in planning for the use of renewable energy resources in water resources development. These include:

- Reliability
- Availability of power
- Cost of power, including transmission
- Institutional and environmental constraints

4.2.1 RELIABILITY

To be suitable for providing power to water resources development, the renewable energy technology should be proven and reliable. For example, for irrigated crops the inability to deliver water at critical times can result in the loss of a crop. Water storage facilities can be provided to ensure that water is available when the renewable resource is not. This involves a tradeoff between the costs of a more reliable power source and the increased costs associated with providing various amounts of storage. Excessive storage requirements can adversely affect project feasibility.

4.2.2 AVAILABILITY OF POWER

To support water resources development, there must be sufficient generation available to meet the pumping and other energy requirements of the water resources development. As discussed above, water storage can be used to "reshape" the power supply. That is, water can be pumped off-peak, stored, and then delivered at appropriate times. In the case of geothermal development on the Big Island, surplus off-peak capacity could be used.

In addition, the renewable energy must be available in a time frame that is comparable to that of the anticipated water development needs. The water development requirements are described in Sections 2 and 3 of this report.

4.2.3 COST OF POWER

The cost of power is an important consideration. If it is too high, the water resources development may be infeasible. The cost of power from the utility will be determined by the retail rate tariffs of the utility. These tariffs are regulated by the State Public Utility Commission (PUC).

On the Big Island, water resource projects currently purchase power from HELCO under either Schedule P, Large Power Service rate schedule, or Schedule M, Off-Peak Curtailable Service rate schedule. The cost of power under these rate schedules is dependent on the demand (kW), energy use (kWh), and time of use. We estimate that the approximate cost under the current Large Power Service rate would average about 11.5 cents per kWh. Under the Off-Peak rate, it would be somewhat less than 10 cents per kWh.

A major contributor to the cost of providing electric service to any utility in Hawaii is the cost of generating the power. Because the majority of the electric power generation in Hawaii is oil-fired, the costs of generation are very sensitive to fuel costs. When the utility purchases power from a renewable resource developer, it pays "avoided costs" for the power. The utility would incur avoided costs if it were to purchase power from a power resource developer, rather than generate the power itself. Avoided costs generally include the fuel that would be displaced and other variable costs. They may also include capacity-related costs if the purchase allows the utility to postpone additional investment in generating capacity. Table 4.2 shows the third quarter 1986 and projected 1991 avoided costs for HELCO, HECO, and MECO. It can be seen that these costs are relatively low, ranging from 3.0 to 3.84/kWh, and are considerably less than the retail rates for power.

It is the avoided cost that any power resource developer could expect to receive from the sale of power to the utility. This price is independent of the cost of generating the power. If generation costs less than the avoided cost, the developer makes money; if it costs more, the developer loses money.

Table 4.2
Avoided Energy Costs

Utility	Supply Type	¢/kwh 1986	1991
HECO	on-peak	3.77	3.66
(Oahu)	off-peak	3.02	3.01
HELCO	on-peak	3.58	3.63
(Hawaii)	off-peak	3.05	3.06
MECO	on-peak	3.58	3.54
(Maui)	off-peak	3.38	3.44

Source: (NECO, July 1986; NELCO, July 1986; and MECO, July 1986)

Table 4.3
ASSESSMENT FOR USE IN WATER RESOURCES DEVELOPMENT

Renewable Energy Technology	Reliability	Availability of Power	Costs	Environmental Constraints	General Feasibility For Use in Water Development
Geothermal	Proven reliability at existing sites.	Large power resource, adequate for large-scale water resources development.	Reasonable.	Very site dependent.	Very good.
OTEC	Currently being pilot-tested; expected to be reliable after further development.	Power resource adequate for smaller water resources development.	Relatively high cost in near term.	Very site dependent.	Good in long term.
Wind	Proven technology, but dependent on weather conditions.	Limited by reliability concerns.	Reasonable.	Very site dependent.	Good, depends on weather conditions.
STEC	The technology is recently available, and with refinements should be reliable, but depends on weather conditions.	Power resource adequate for smaller-scale water resources development.	Reasonable.	Very site dependent.	Good, depends on weather conditions.
Hydroelectric	Well proven, but depends on water supply.	Relatively small power potential on the islands.	Reasonable.	Very site dependent.	Very good, especially if incorporated into the water development project.
Pumped Storage	Well proven.	Relatively small power potential on the islands.	Reasonable.	Very site dependent.	Very good, especially if incorporated into the water development project.
Biomass and MSW Conversion	Well proven, depends on biomass or MSW supply.	Most of capacity is already committed.	Reasonable.	Very site dependent.	Good.

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The utility may require a developer, whether of a renewable resource or a water resource, to pay for all, or a portion of, the costs of any transmission system improvements required to provide transmission service.

The existing large capacity HELCO transmission systems are shown in Figure 4.1. (Note a 138-kV system over the saddle is currently under construction and will be added to Figure 4.1 in the final draft.) If large-scale geothermal development on the Big Island takes place, the island's transmission system will have to be expanded to accommodate the project. Additional transmission capability, possibly at 115 kV, will be required to transmit the power to the landfall of the HDWC.

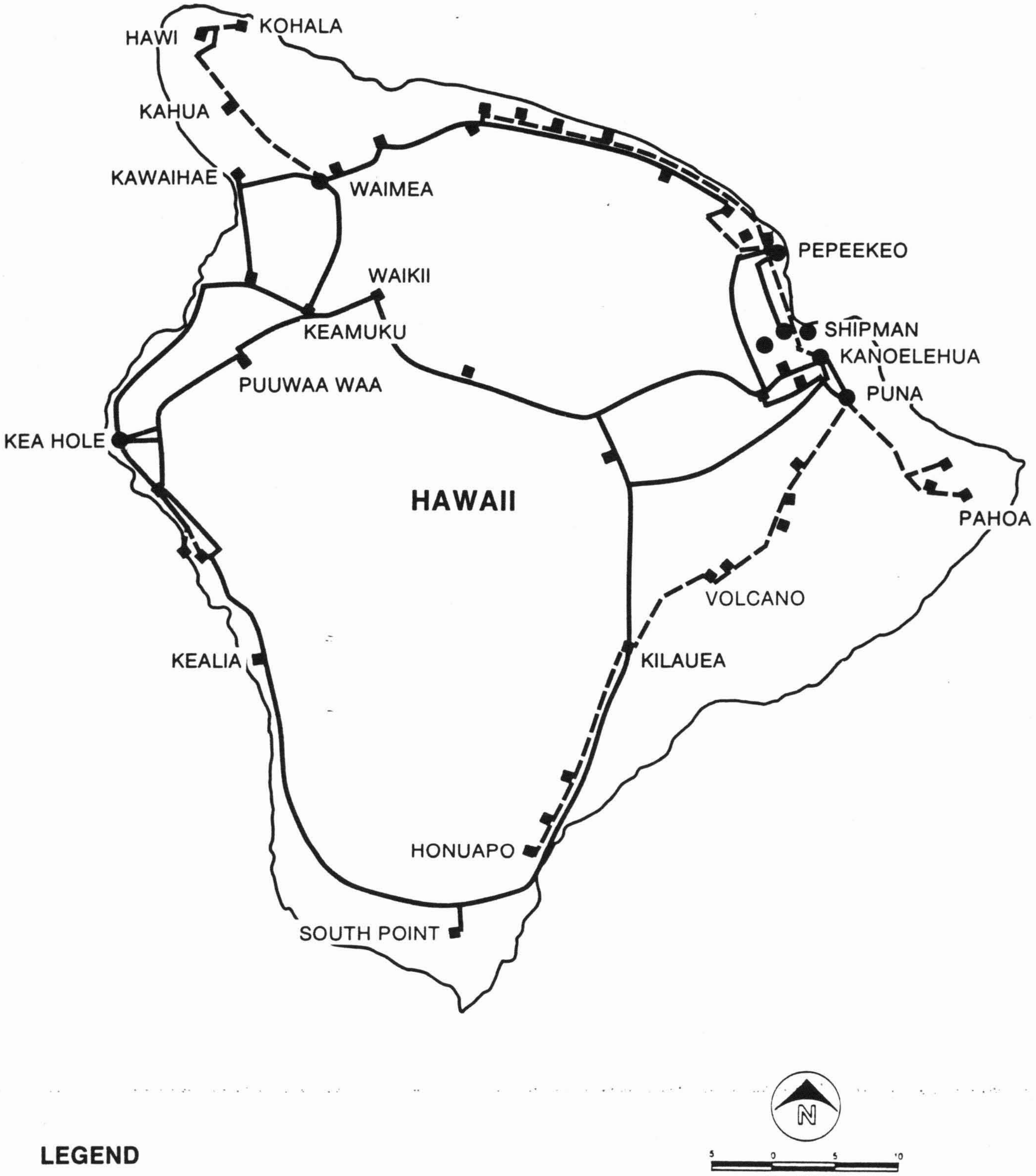
Considerable effort has gone into determining the feasibility of the HDWC. Its primary purpose would be to transmit geothermal power from the Big Island to the load centers on Maui and Oahu. The proposed capacity of the line is 500 MW. Figure 4.2 shows the route assumed for this study (HECO, April 1986). This route includes a landfall on Maui. The completion of the HDWC is assumed to coincide with the expected development of the geothermal resource, which is in about 1995.

Transmitting geothermal power from the Big Island will require that HDWC terminal facilities be constructed on the Big Island, and that the existing transmission system be upgraded to bring the power to these facilities. Transmission system improvements will also be required to make use of the geothermal energy on Oahu and Maui. The extent of these improvements have not been determined.

4.2.4 INSTITUTIONAL AND ENVIRONMENTAL CONSTRAINTS

Before a renewable resource can be relied upon for water resources development, it must comply with local, state, and federal regulations with regard to land use, water quality, air quality, noise, fish and wildlife, and a number of other issues. These are different for each renewable energy technology.

The Hawaii Integrated Energy Assessment (DPED and Lawrence Berkeley Laboratory, 1981) included an analysis of the major environmental, legal, social, and institutional constraints on implementation of the various renewable energy resource technologies. All of the technologies have associated institutional and environmental constraints that are generally site-specific and that often require mitigation. A summary of the potential constraints for each of the technologies and for development of the HDWC follows:



LEGEND

- ● Power Plant
- ■ Substation
- ——— 69 KV Line
- – – – – 34.5 KV Line

Figure 4.1
EXISTING HELCO
TRANSMISSION SYSTEM

CH2M HILL

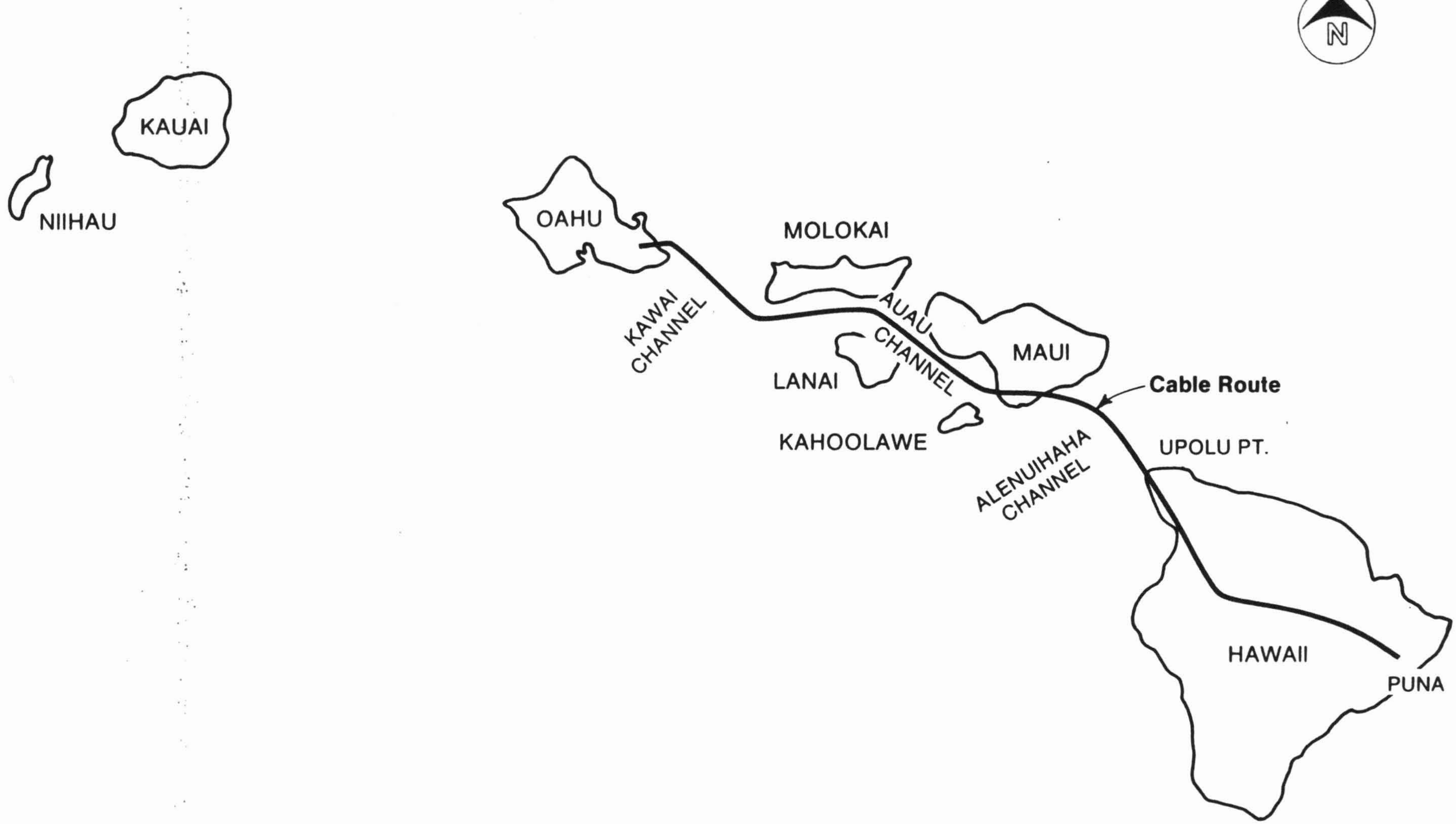


Figure 4.2
ASSUMED DEEP WATER CABLE ROUTE

o	Geothermal	Toxic fumes, noise; industrial use of Hawaiian Home Lands; questions of ownership of rights to geothermal resources; industrial development of new rural areas; potential for volcanic destruction of facilities
o	OTEC	Construction state requirements for large land area near beaches and marine facilities already in short supply, possible influx of workers; operating state interference with underwater fuel lines and other cables and with surfing and swimming sites; water pollution from accidental discharge of working fluid; possible adverse effects from changes in thermal gradients or ocean temperatures
o	Wind	Visual impact of large arrays, subsonic or audible noise disturbing humans and animals; possible danger from broken or thrown blades; possible interference with flight operations and TV reception
o	STEC	Considerable site disturbance; danger from misdirected high temperature radiation; glare interfering with flight operations; uncertainties concerning solar rights; land use issues
o	Photovoltaics	Pollution and health and safety problems with manufacturing and decommissioning toxic semiconductor materials, site disturbance and land use issued for central systems arrays; uncertainties concerning solar rights
o	Hydroelectric	Danger of flash floods and downstream damage if dams fail, disturbance of impoundment site; legal questions concerning ownership of water and water use rights
o	Pumped storage	Danger of flash floods, environmental impacts at impoundment site, potential for salt water intrusion into fresh water supplies if salt water is used; legal questions concerning ownership of water and water use rights
o	Biomass	Visual and noise pollution; competing land uses; potential for erosion; loss of recreational forest and open lands and other archaeological sites; toxic spillage discharge; competing markets for biomass resources
o	MSW	Air and water pollution; increased noise and traffic from municipal solid waste trucking operation
o	HDWC	Visual impact and possible damage to swimming and surfing sites where cables come on shore; navigational hazards during cable-laying and repair; laws of international waters and navigation rights; little or no damage to deep marine environment expected

4.3 GENERAL FEASIBILITY OF THE RENEWABLE ENERGY TECHNOLOGIES FOR WATER RESOURCES DEVELOPMENT

The renewable energy technologies were analyzed in terms of their reliability, availability of power, costs, and institutional and environmental constraints to indicate their general feasibility for use in water resources development. All of the technologies considered in this study, with the exception of solar photovoltaics, appear generally suitable. The cost of photovoltaics is relatively high, making that technology impractical for major use in any sizable water development project. The general feasibility of the other technologies is summarized in Table 4.3.

Geothermal energy is quite feasible for use in water resources development. It is a well proven technology; large amounts of energy production are expected to be possible on the Big Island, and its development costs are reasonable. The institutional and environmental constraints on geothermal, as with all the technologies, is very site-specific. Hydroelectric and pumped storage are also rated as having very good feasibility, especially if they are incorporated into the water development project. These technologies are well proven and have reasonable development costs.

OTEC feasibility is somewhat less, especially in the near-term, because it is still under development and it is expected to be relatively costly. Wind is a proven technology; its rating, however, is reduced because of its dependence on favorable weather conditions. STEC technology is still being refined and also depends on favorable weather conditions. Its costs are reasonable, however, and it could produce adequate energy for smaller water development projects. STEC is rated as having good feasibility for use in water resources projects. Biomass and MSW conversion also have good feasibility for use in water resources development. They are proven technologies and they are currently in widespread use. Their energy production, however, is already committed to current uses.

4.4 FRAMEWORK FOR PROJECT DEVELOPMENT

As noted in the foregoing, several renewable energy technologies could be used to develop water resources on the islands. The main emphasis in this study, however, is to look at using geothermal power from the Puna area of the Big Island.

Two sizes of geothermal projects, 50 MW and 500 MW, were considered in developing the study framework. The 50 MW size is indicative of the low end of the probable range of geothermal power that may be developed on the Big Island. This size project could be developed without completion of the deep water cable. The high-end project assumes the deep water cable would be completed and that up to 500 MW of geothermal power would be transmitted to Oahu and Maui. For both sizes of projects it is assumed that existing generation capacity (mainly oil fired) would provide most of the baseload. The geothermal power would supply the remainder of the baseload and peak demands.

Unneeded off-peak power would be available for water resources development. This off-peak power could be used on the Big Island or on Oahu and Maui if the deep water cable is completed. Water resources development on just the Big Island is considered in detail in this study.

The electric power needs on the islands, the availability and use of the excess geothermal energy, and the expected cost of the energy for water resources development form the framework of the conceptual planning that follows in Sections 5 and 6. Year 2000 electric power need conditions were used as the basis of the study.

4.4.1 ELECTRIC POWER NEEDS

Power needs affect the timing and availability of excess energy for water resources development. Estimated power needs on the Big Island, Oahu, and Maui were developed from power company projections and are presented in the form of diurnal demand curves in Figures 4.3 through 4.5.

Figure 4.3 shows the projected HELCO (Big Island) hourly power demands in 2000. Figure 4.4 shows the HECO (Oahu) hourly power demands in the year 2000, after the 500 MW Puna geothermal and the deep water cable projects are expected to go online. Figure 4.5 shows the Maui Electric Company (MECO) hourly power demands in 2000. The Maui power demands are slightly larger than the Big Island demands. The Oahu power demands are about ten times as large as for the Big Island and Maui.

The indicated hourly power demands are for average day conditions. The shape of the daily load curves was computed from monthly weekend and weekday hourly unit load profile data obtained from HECO. The average hourly unit load profiles were multiplied by forecasted peak-day demands to determine the amplitude of the curves.

4.4.2 AVAILABILITY AND USE OF GEOTHERMAL ENERGY

The availability and reliability of geothermal power will greatly affect the resource mix of the electric utilities. Because of reliability considerations, backup generation capacity will be required on each island in order to maintain continuity of service should the HDWC be out of

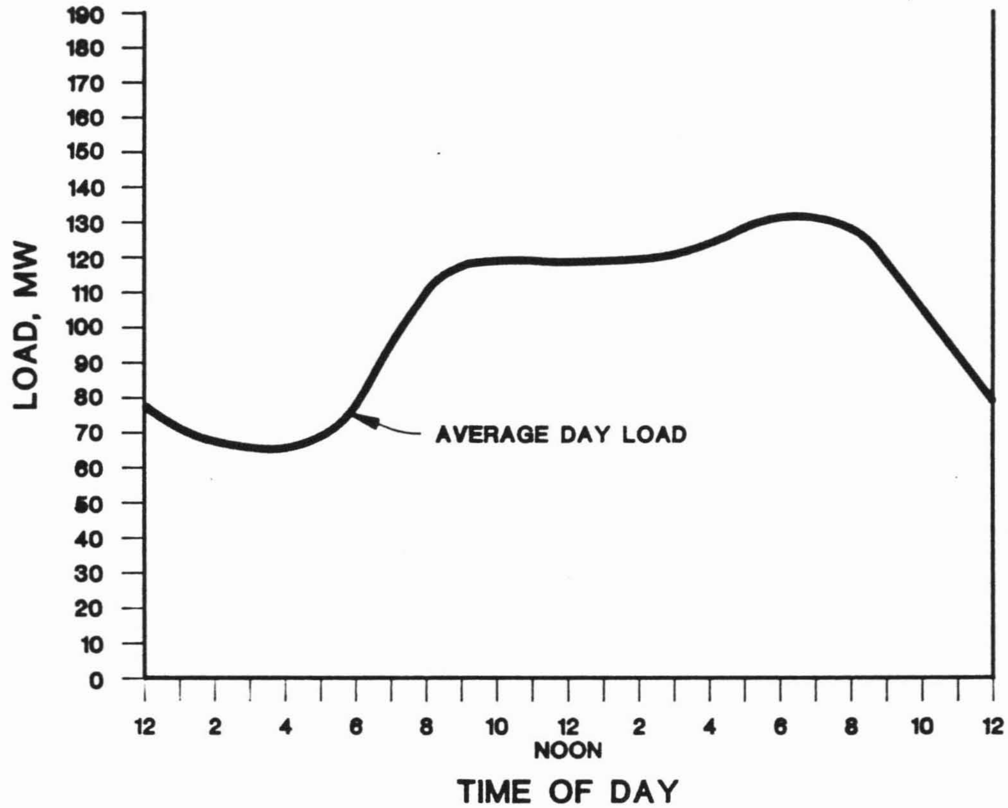


Figure 4.3
HELCO HOURLY POWER
DEMAND - 2000

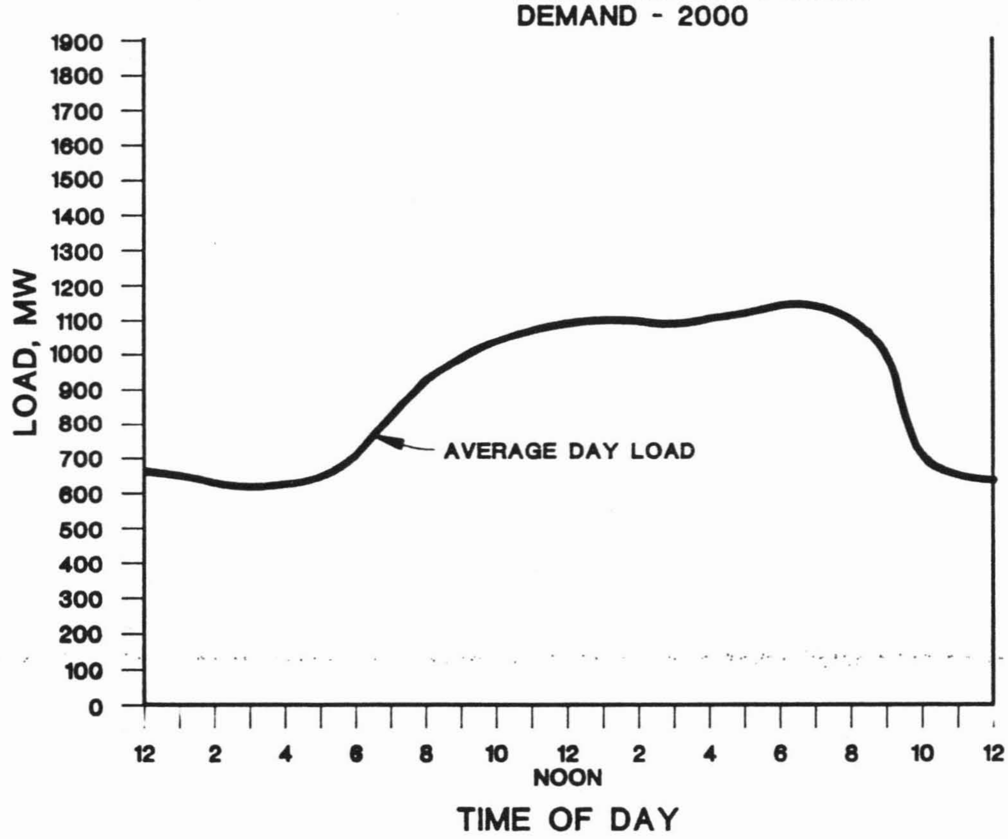


Figure 4.4
HECO HOURLY POWER
DEMAND - 2000

CH2M HILL

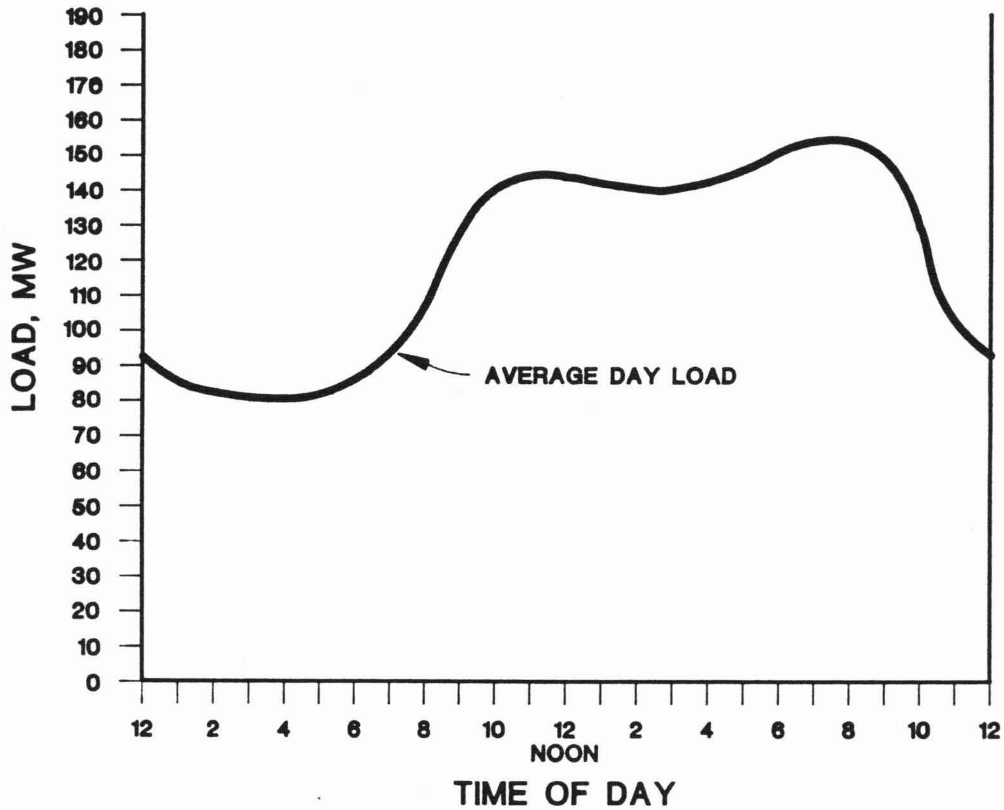


Figure 4.5
MECO HOURLY POWER
DEMAND - 2000

service. There will also be a practical limit to the amount of geothermal power each island can import and still be able to withstand the loss of the HDWC without suffering a major blackout. This consideration may result in some loads being served on an interruptible basis; if the HDWC is tripped out of service, the load will be shed in order to maintain system integrity. HECO is currently working to determine how much of its baseload generation should be on Oahu and how much can be imported. A primary criteria in this determination will be the ability of the system to withstand disturbances caused by both generation and transmission outages, especially by HDWC.

If the HDWC is transmitting a large portion of the Oahu power needs and is tripped out of service for some reason, the generation on Oahu may not be sufficient to carry the island's loads. If this is the case, the Oahu generation will be tripped out of service by protective relaying and a blackout of the island might result.

Another consideration will be the ability of the geothermal generation to be cycled from one load level to another. The geothermal wells and reinjection wells may not tolerate on-off or cycling modes of operation. This will also affect how much geothermal capacity will eventually be installed.

HECO is evaluating the feasibility of cycling the geothermal power generation. This work is intended to indicate how far the geothermal power generation facilities can be cut back during off-peak demand periods. It is assumed for this study, however, that the geothermal facilities will not be cut back and that full use can be made of the off-peak power in water resources development.

Figure 4.6 indicates an assumed HECO power supply operating plan that was used to estimate the amount of excess geothermal energy available for water resources development in a 500 MW project. Under the operating plan assumed for this study, Oahu oil-fired generation would vary from about 320 MW to 620 MW. The lower value represents the assumed minimum generation capacity on Oahu required for reliability. Ongoing HECO studies are evaluating the feasibility of even lower values, but the 320 MW value was used in this study to be conservative. Total geothermal power production was assumed to remain steady at 500 MW. The amount of power that would be transmitted from the Big Island to Oahu, however, would vary from about 250 MW to 500 MW. The excess energy under this operating plan, which is assumed available for water resources development, totals about 1,000,000 MWh per year. As shown in Figure 4.6, the bulk of the excess geothermal energy will be available from about 10:00 p.m. to 8:00 a.m., a period of 10 hours.

Figure 4.7 shows the assumed power supply operating plan for use of up to 50 MW of geothermal power on the Big Island. Under this operating plan, local oil-fired generation would provide 50 to 80 MW of power. Total geothermal power production would be 50 MW, with 15 to 50 MW being used by HELCO. Excess energy would total about 120,000 MWh per year.

Figure 4.8 indicates the order-of-magnitude of water resources development that could be accomplished with the excess geothermal energy. The figure shows potential pumping rate versus lift with 120,000 and 1,000,000 MWh per year of excess energy. These curves were developed assuming 10 percent hydraulic friction and minor losses in addition to the static lift. The curves do not account for hydroelectric energy production that may be possible in some integrated water/energy projects.

With 120,000 MWh of energy per year, 20 mgd could be lifted about 3,000 feet and 200 mgd could be lifted about 300 feet. With 1,000,000 MWh/year, 80 mgd could be lifted 6,600 feet and 200 mgd could be lifted about 2,500 feet.

4.4.3 COST OF THE GEOTHERMAL ENERGY FOR WATER RESOURCES DEVELOPMENT

At this time, it is not possible to accurately estimate the cost of obtaining the excess geothermal energy for use in a water resources project. The cost will depend on the geothermal developer's cost of producing the electrical energy, whether the energy is obtained directly from the developer or through the power utility, transmission costs, and the effect of PUC requirements. Therefore, a range of energy costs was used in estimating the operating costs for the conceptual integrated water/energy projects. The lower end of the energy cost range is 3 cents per kWh, which is about equal to current avoided energy costs. The high end of the range is 12 cents per kWh, which is near the current Large Power Service rate. The water development costs will be estimated in terms of $/thousand gallons, with both the low and high energy costs to determine the potential cost savings using the excess geothermal energy.

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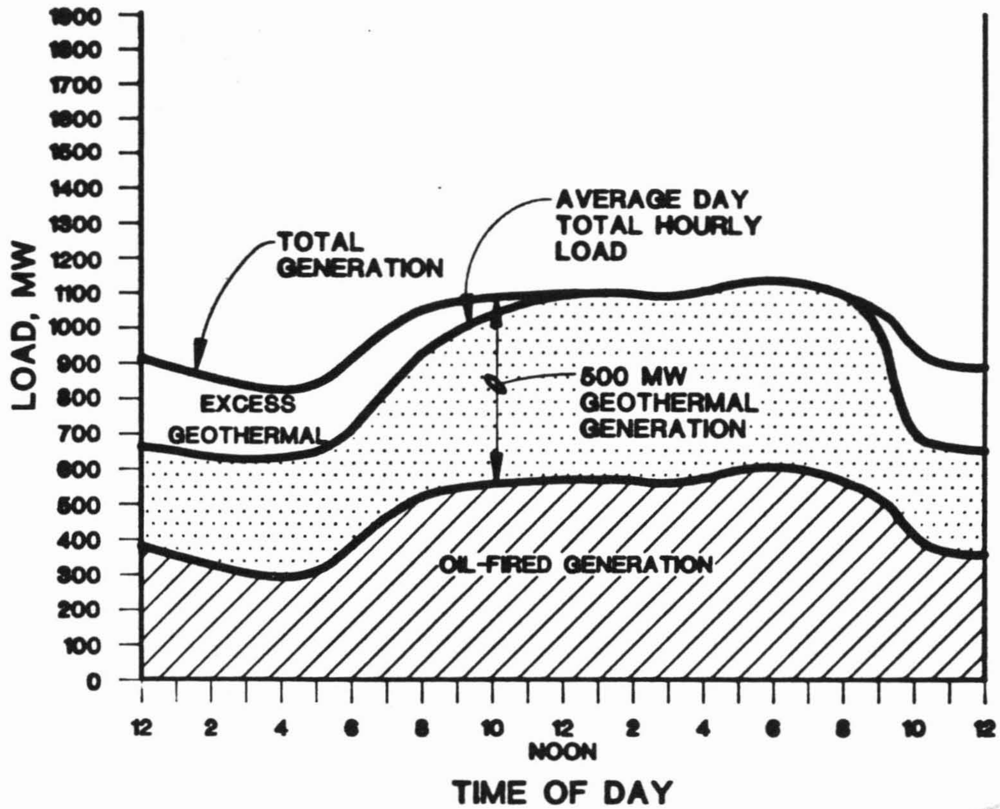

Figure 4.6
YEAR 2000 OAHU POWER SUPPLY WITH 500 MW GEOTHERMAL GENERATION

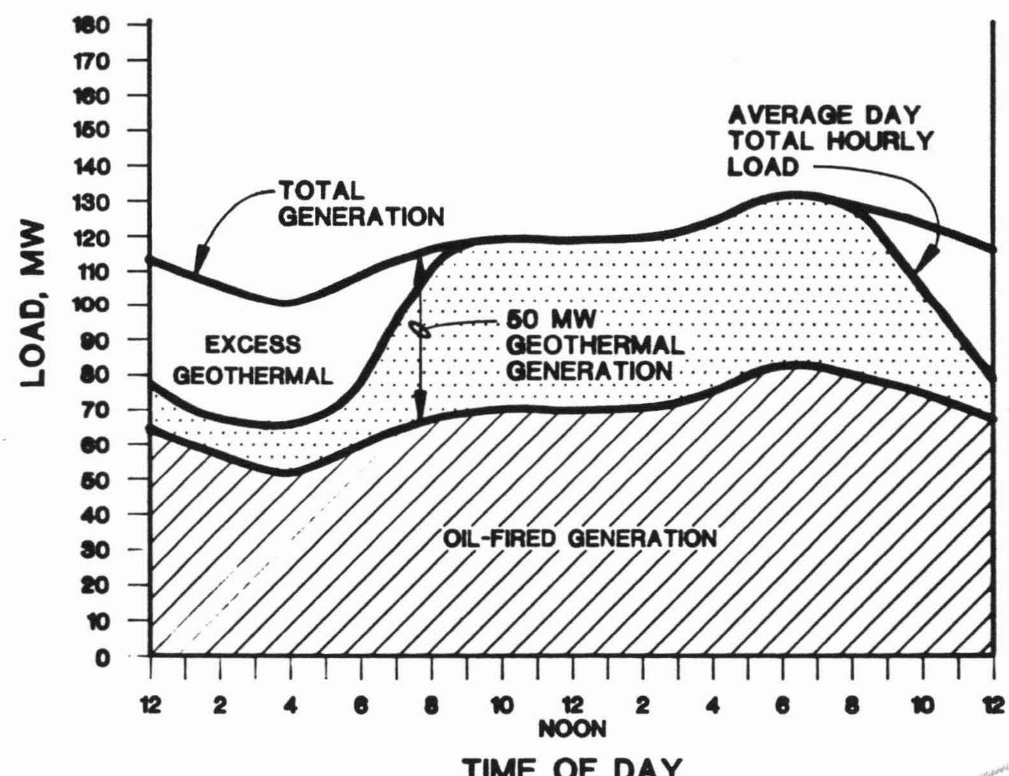

Figure 4.7
YEAR 2000 BIG ISLAND POWER SUPPLY WITH 50 MW GEOTHERMAL GENERATION

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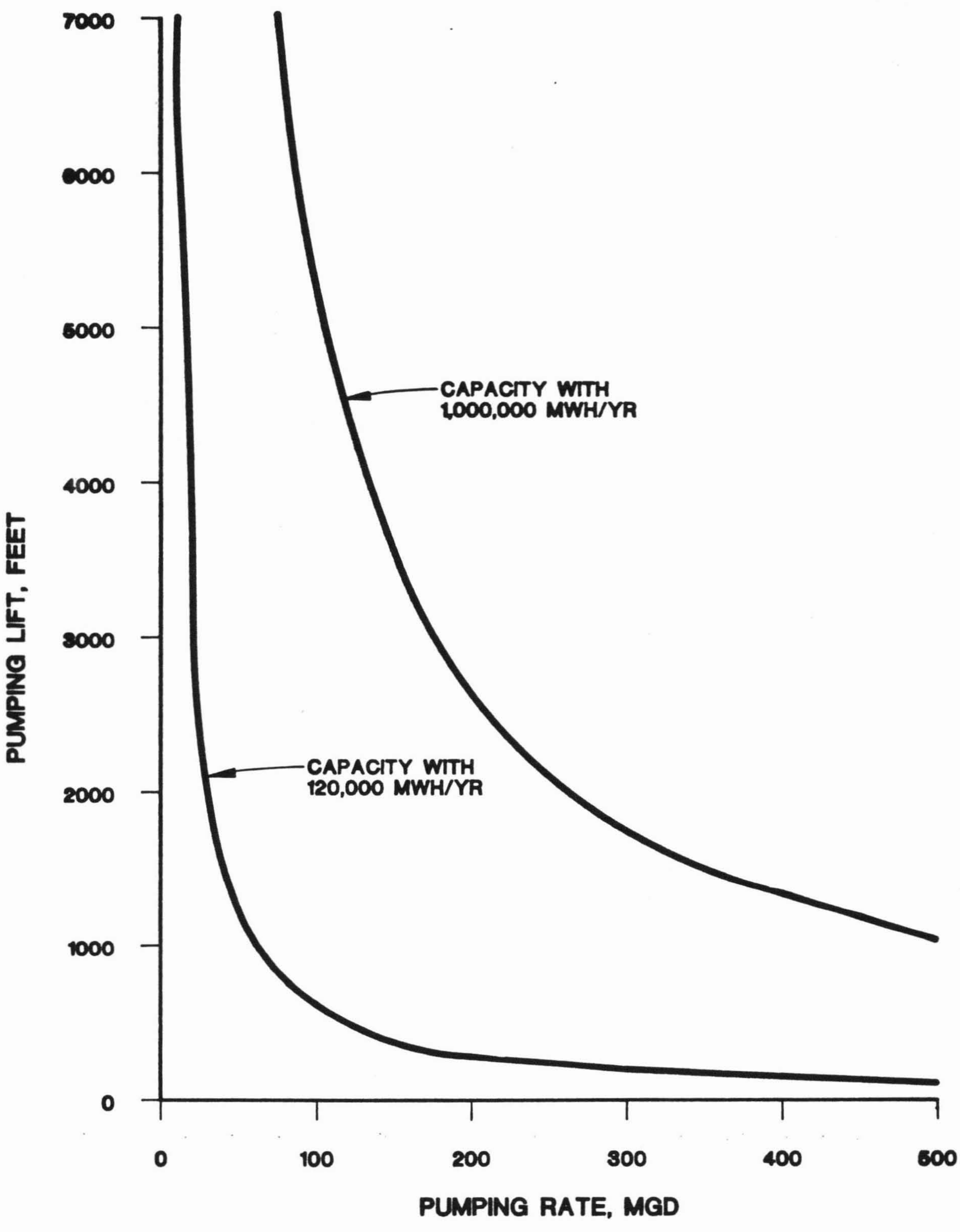


Figure 4.8
PUMPING CAPACITY WITH
EXCESS GEOTHERMAL ENERGY

CH2M HILL

Section 5
IDENTIFICATION OF POTENTIAL WATER/RENEWABLE ENERGY PROJECTS

Several potential integrated water/renewable energy projects were identified. These were based on the foregoing assessment of water needs and means of development, and the renewable energy resources assessment. The potential projects are described and evaluated in this section.

5.1 DESCRIPTION OF POTENTIAL PROJECTS

Twelve potential projects were identified and are described in Table 5.1. Figures 5.1 through 5.12, included at the end of this section, are conceptual depictions of the projects. The potential projects generally fall into one of two categories: Those identified with a "W" would involve use of excess geothermal energy to move water from the collection site to where it is needed. In those alternatives identified with an "E," the excess energy would first be transmitted to the dry side of the island and then be used to develop local water sources.

Some potential projects were also identified combining the alternatives. These alternatives, which are identified as "EW," include long-distance electrical power transmission to the water collection site, followed by using the excess energy to move water to where it is needed.

Alternatives W-1 and W-2 are similar and would consist of pumping Wailuku River flows over the saddle between Mauna Kea and Mauna Loa to the leeward side of the island. Water would be diverted from the river in the reach between the 2,000- and 4,000-foot elevations. The water would be collected and stored in a reservoir from 8:00 a.m. to 10:00 p.m. and would then be pumped during the off-peak period of 10:00 p.m. to 8:00 a.m., when excess geothermal energy is available. A flow-equalizing and emergency storage reservoir would be provided on the west side of the saddle. The water would then be delivered by gravity flow to sites where it is needed. Storage would also be provided near the sites so that hourly water demand variations could be matched. A suboption to these alternatives would be to include hydroelectric generation to recapture a portion of the energy used in pumping the water over the saddle. In Alternative W-1, about 18 mgd of water would be provided to the coastal portions of Area V to supply domestic needs. Alternative W-2 would provide more water--a total of 34 mgd--to the coastal portions of Hydrographic Areas IV and V. These alternatives would include treatment to make the water suitable for domestic use.

Table 5.1
POTENTIAL INTEGRATED WATER/RENEWABLE ENERGY ALTERNATIVES

ALTERNATIVE	WATER SOURCE, QUANTITY	WATER/ENERGY TRANSMISSION	WATER USE, LOCATION	SUB-OPTIONS	COMMENTS
W-1	Area II--Upper reaches of Wailuku River, 18 mgd	Water, pipeline over saddle	Domestic, Coastal Area V	Hydroelectric generation	High capital cost, water treatment required
W-2	Area II--Upper reaches of Wailuku River, 34 mgd	Water, pipeline over saddle	Domestic, Coastal Areas IV & V	Hydroelectric generation	High capital cost, water treatment required
W-3	Area II--Basal ground-water, Laupahoehoe to Kapoho, 34 mgd	Water, pipeline over saddle	Domestic, Coastal Areas IV & V	Hydroelectric generation	High capital cost, long distances to areas of use
W-4	Area II--Basal ground-water, Laupahoehoe to Kapoho, 211 mgd	Water, pipeline over saddle	Domestic, Coastal Areas IV & V; and Agri-culture, near Waimea	Hydroelectric generation	High capital cost, extensive well field required, long distance to areas of use, and institutional concerns for transfer of large quantity of groundwater
E-1	Area V--Potable basal groundwater, Hawi to Keahole, 18 mgd	Energy, transmission line over saddle	Domestic, Coastal Area V		Low capital cost; well development can be staged
E-2	Areas IV & V--Potable basal groundwater, Hawi to Keahole, 18 mgd; and Keahole to Hookena, 16 mgd	Energy, transmission line over saddle	Domestic, Coastal Areas IV & V	16 mgd project only, with water develop-ment only in Area IV	Low capital cost; well development can be staged
E-3	Area V--Brackish basal groundwater, Hawi to Keahole, 18 mgd	Energy, transmission line over saddle	Desalinization and domestic use, Coastal Area V		Well development can be staged; requires desaliniza-tion

Table 5.1
POTENTIAL INTEGRATED WATER/RENEWABLE ENERGY ALTERNATIVES
(continued)

ALTERNATIVE	WATER SOURCE, QUANTITY	WATER/ENERGY TRANSMISSION	WATER USE, LOCATION	SUB-OPTIONS	COMMENTS
E-4	Area IV--Brackish basal groundwater, Keahole to Hookena, 16 mgd	Energy, transmission line over saddle	Desalinization and domestic use, Coastal Area IV	E-3 and E-4 combined	Well development can be staged; requires desalinization
EW-1	Area I--Potable basal groundwater, Waipio Valley to Kukaiau, 18 mgd	Energy, transmission line to water collection area; and water, pipeline via Waimea	Domestic, Coastal Area V		Fair water availability because water source is being considered for use in Area I; well development can be staged
EW-2	Area I--Potable basal groundwater, Waipio Valley to Kukaiau, 34 mgd	Energy, transmission line to water collection area; and water, pipeline via Waimea	Domestic, Coastal Areas IV & V		Fair water availability because water source is being considered for use in Area I; well development can be staged
EW-3	Areas I & II--Hamakua Coast streams, 34 mgd	Energy, transmission line over saddle; and water, pipeline via Waimea	Domestic, Coastal Areas IV & V		High source development costs, water treatment required
EW-4	Areas I & II--Hamakua Coast streams, 211 mgd	Energy, transmission line over saddle; and water, pipeline via Waimea	Domestic, Coastal Areas IV & V; and Agriculture, near Waimea	Agriculture use only	High source development costs, water treatment required, and institutional concerns for transfer of large quantity of water

Alternatives W-3 and W-4 would use wells to collect potable basal groundwater in the area between Laupahoehoe to Kapoho, and would require pumping the water over the saddle to the leeward side of the island. Pumping would be done during the off-peak energy demand period. Storage would be provided near the top of the saddle, and the water would be delivered from there by gravity flow. Alternative W-3 would provide 34 mgd for domestic use in Areas IV and V. Alternative W-4 would also provide water for irrigation of the "prime-if-irrigated" lands near Waimea. This requires a total flow of 211 mgd. Generation of hydroelectric power could be a suboption to both alternative W-3 and W-4.

In Alternatives E-1 and E-2, the excess geothermal energy would first be transmitted to the leeward side of the island, where local water resources would be developed. It is assumed that the transmission system would follow the Saddle Road route. Existing transmission lines would be used if possible. Potable basal groundwater would be collected using wells located above the 1,200-foot elevation. Off-peak excess geothermal energy would be used to operate the wells. The wells would be spaced along the coastal area to facilitate service demand and to minimize interference among wells. Storage would be required for each well to equalize the water supply with the hourly demands. Alternative E-1 would provide 18 mgd for domestic use in coastal portions of Area V. Alternative E-2 would include groundwater development and use in Area IV, and would supply a total flow of 34 mgd. Well development could be staged as water demands increase.

Alternatives E-3 and E-4 are similar to Alternatives E-1 and E-2; however, the wells would be located at a lower elevation and they would collect brackish water. Desalinization would be required to make the water suitable for domestic use. The off-peak period excess geothermal energy would be used for operating the wells and for the desalinization process. Storage would be required to equalize the water supply with hourly water demands. Alternative E-3 would provide 18 mgd for domestic use in the coastal portions of Area V. Alternative E-4 would provide 16 mgd for domestic use in Area IV. The wells could be constructed in stages to provide more water as demands increase over time.

Alternatives EW-1 through EW-4 involve transmitting off-peak excess geothermal energy from the Puna area to an area near Waimea and Honokaa to develop water supplies there. The water would be pumped to the leeward side of the island, past Waimea, for use in Areas IV and V.

Alternatives EW-1 and EW-2 would include the use of wells to collect potable basal groundwater from the area between Waipio Valley and Kukaiau. In Alternative EW-1, 18 mgd would be developed for domestic use in the coastal portions of Area V. In Alternative EW-2, the system would be expanded to also serve the coastal portions of Area IV. The off-peak excess geothermal energy would be used to both operate the wells and to pump the water through the Waimea area.

In Alternatives EW-3 and EW-4, surface waters would be collected from Hamakua Coast streams. A combination of canals and pipelines would be used to collect the water in a reservoir located between Honokaa and Kukaiau. The off-peak excess geothermal energy would be used to pump the water through the Waimea area. In Alternative EW-3, 34 mgd would be developed for domestic use in Areas IV and V. In Alternative EW-4, 211 mgd would be developed to include agricultural use in the Waimea area. The agricultural use would require some additional pumping to serve higher elevation lands. The water used for domestic purposes would require treatment, and storage would be required to match hourly demands.

Many other alternatives and combinations of alternatives were also identified, but were screened from further consideration because of serious concerns regarding engineering feasibility, reliability of water supply, and environmental and institutional constraints.

5.2 ASSESSMENT OF POTENTIAL PROJECTS

Major advantages and disadvantages of the 12 alternatives are discussed below.

Alternatives W-1 through W-4 have high initial capital costs because of the long transmission pipeline required over the saddle. These alternatives offer less opportunity for staged construction than some of the other alternatives. Institutional constraints may preclude the collection and transfer of 211 mgd from the wet side of the island to the dry side in Alternative W-4. Alternatives W-1 and W-2 require treatment before domestic use, which places them at a disadvantage when compared to the use of potable groundwater.

Alternatives E-1 through E-4 rely on groundwater development for the water supply. The wells and related storage facilities can be constructed in stages as water demands increase. This reduces the need for high initial capital investment. Alternatives E-3 and E-4 require desalting of the brackish groundwater before use. Therefore, Alternatives E-3 and E-4 have higher initial capital and annual operating costs than Alternatives E-1 and E-2.

Alternatives EW-1 and EW-2 rely on the potable basal groundwater between the Waipio Valley and Kukaiau areas. This source of water has been considered for development and use in Waimea and for other local areas. Thus, these alternatives have only fair feasibility because of the potential institutional constraints on use of this groundwater source in areas outside of Hydrographic Area I.

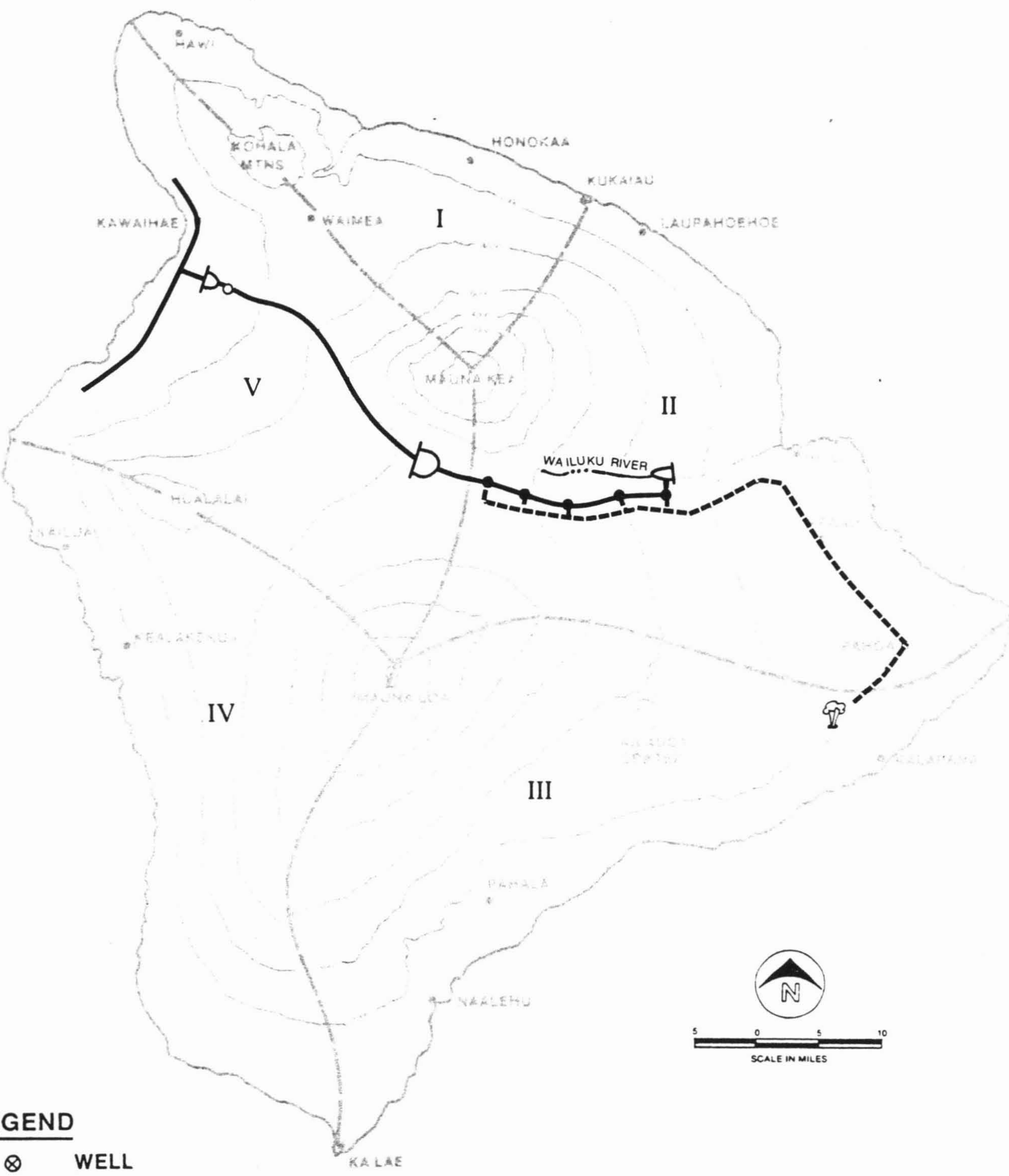
Alternatives EW-3 and EW-4 call for the development of surface water sources, which would require treatment before domestic use. The canal and pipeline collection system would require a high initial capital cost.

5.3 PROJECT SELECTION

Alternatives W-1 and E-1 were selected for further analysis in a meeting with DPED and DOWALD representatives. These alternatives were selected because they represent two general categories of potential integrated water/renewable energy projects. These general categories are: (a) use of the excess energy to develop the water source on the wet side of the island and then pumping the water to the dry side, and (b) transmitting the energy to the dry side of the island for use in developing local water sources.

The former project, Alternative W-1, represents a visionary look at what could be done to use off-peak excess energy. The latter project, Alternative E-1, would use the energy to develop water resources in a more traditional manner, deep well pumping, to see what advantages may accrue to the Department of Water Supply or other water developers.

Comparing the two projects will provide decisionmakers with a better understanding of the total range of costs, benefits, technical feasibility, and environmental and institutional constraints involved in an integrated water/renewable energy project. The two alternatives are similar in size, so economics of scale will have the same effect on both alternatives. Alternative W-1 will be developed with and without hydroelectric generation so that the costs and benefits of that suboption can be assessed.



LEGEND

- ⊗ WELL
- ● PUMP STATION
- o HYDROELECTRIC PLANT
- PIPELINE
- CANAL
- ELECTRICAL TRANSMISSION LINE
- RESERVOIR
- GEOTHERMAL PLANTS

Figure 5.1
ALTERNATIVE W-1

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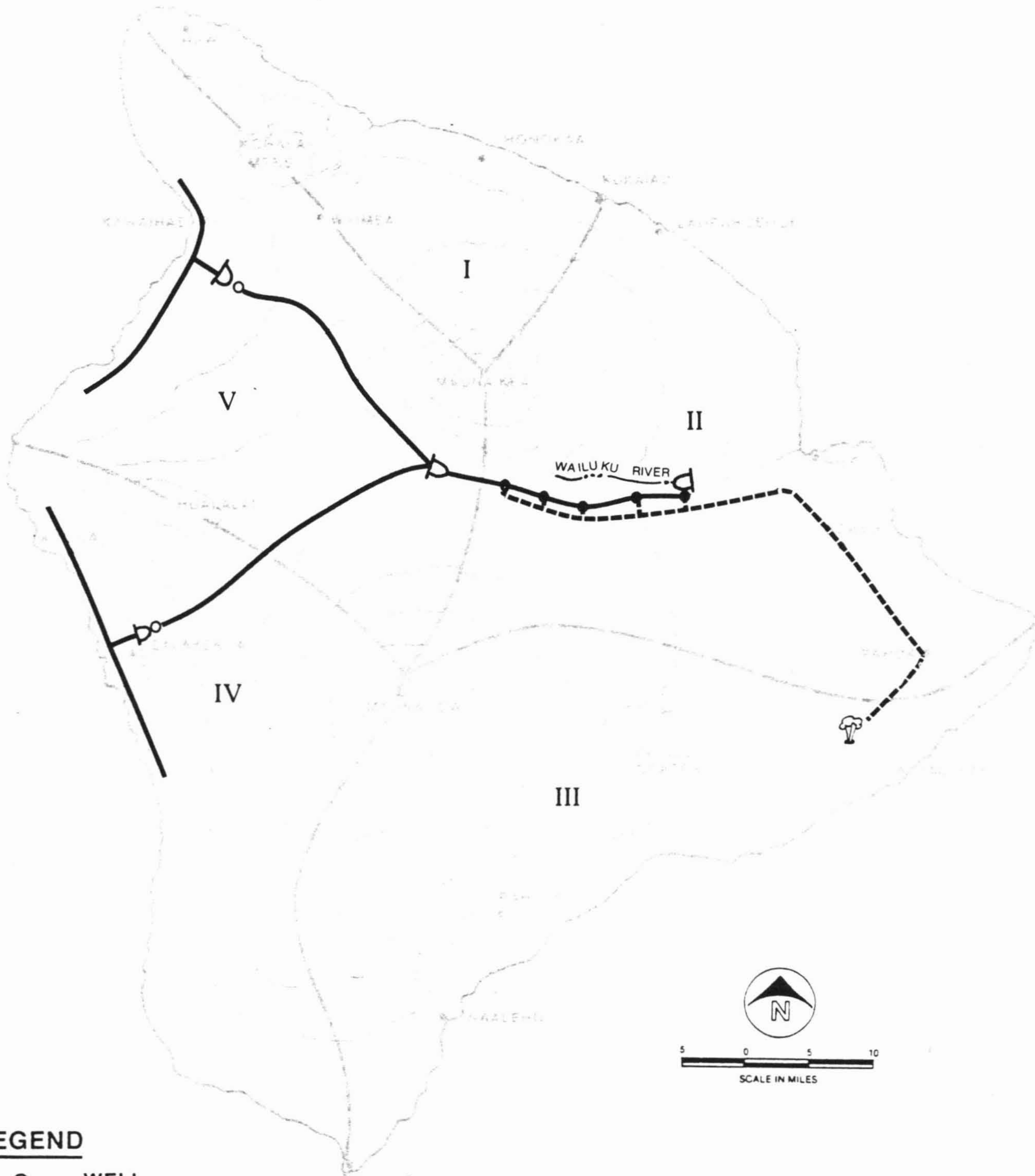


LEGEND

- ⊗ WELL
- ● PUMP STATION
- o HYDROELECTRIC PLANT
- PIPELINE
- CANAL
- ELECTRICAL TRANSMISSION LINE
- RESERVOIR
- GEOTHERMAL PLANTS

Figure 5.2
ALTERNATIVE W-2

CH2M HILL

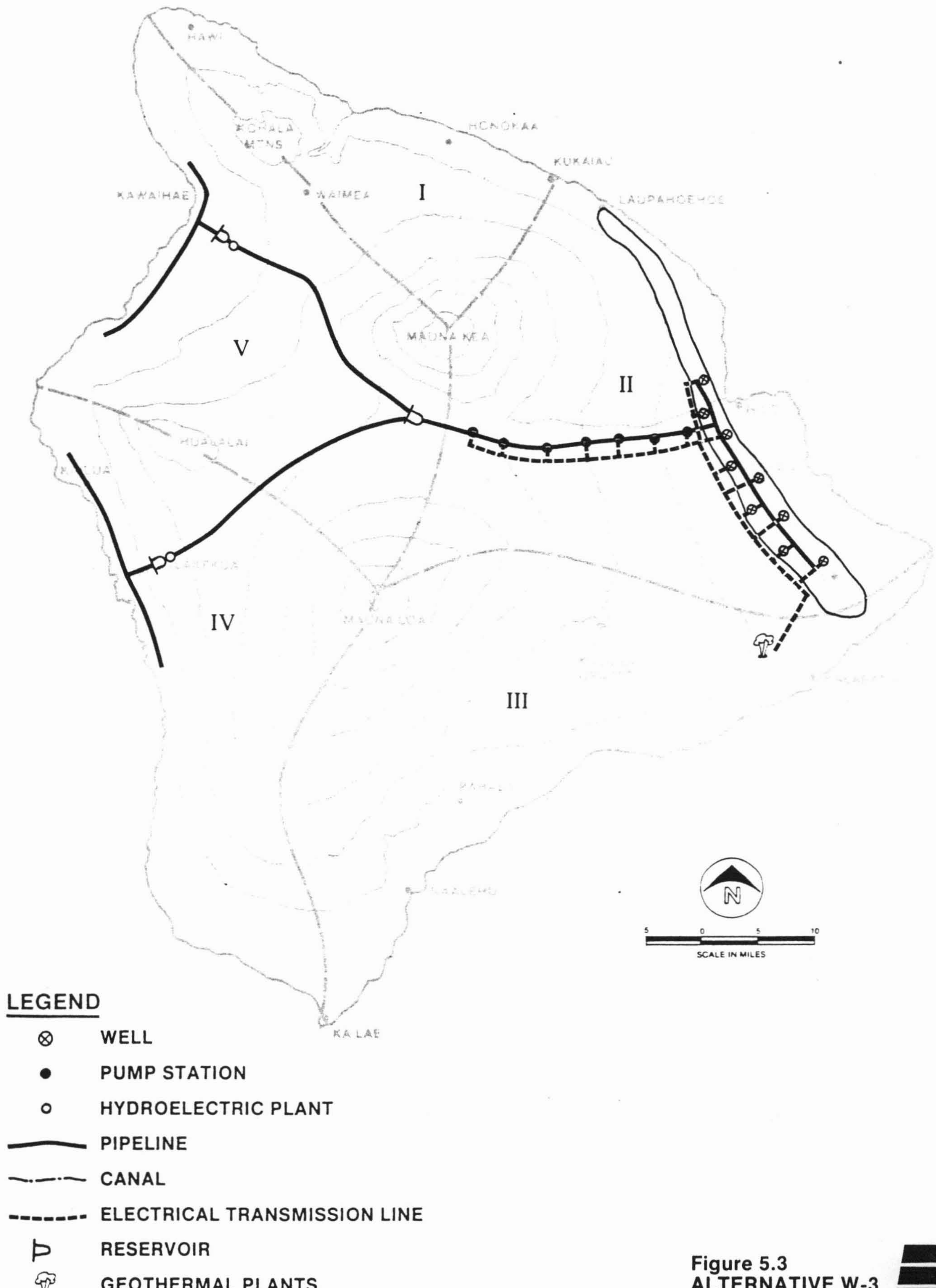


Figure 5.3
ALTERNATIVE W-3

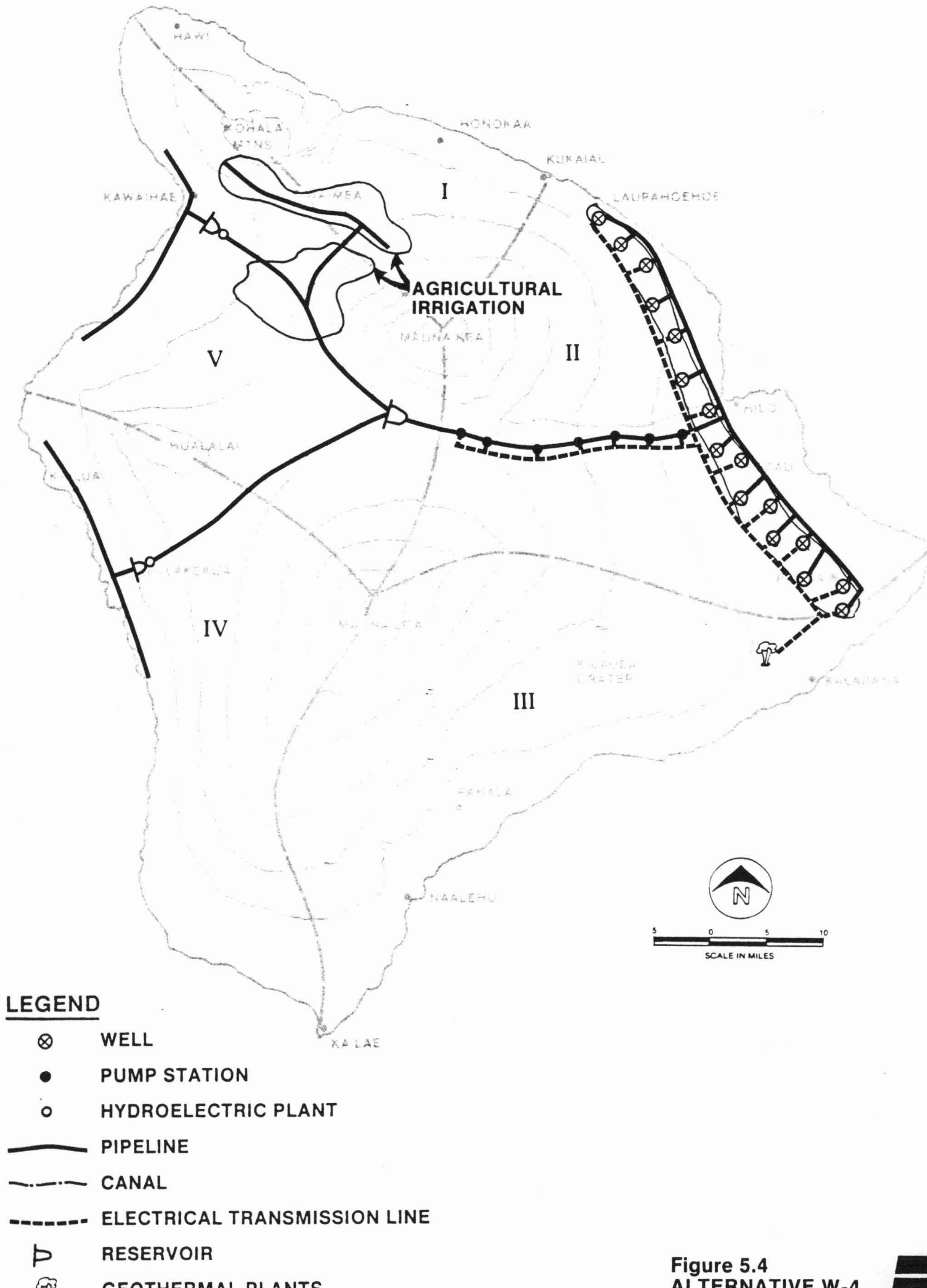
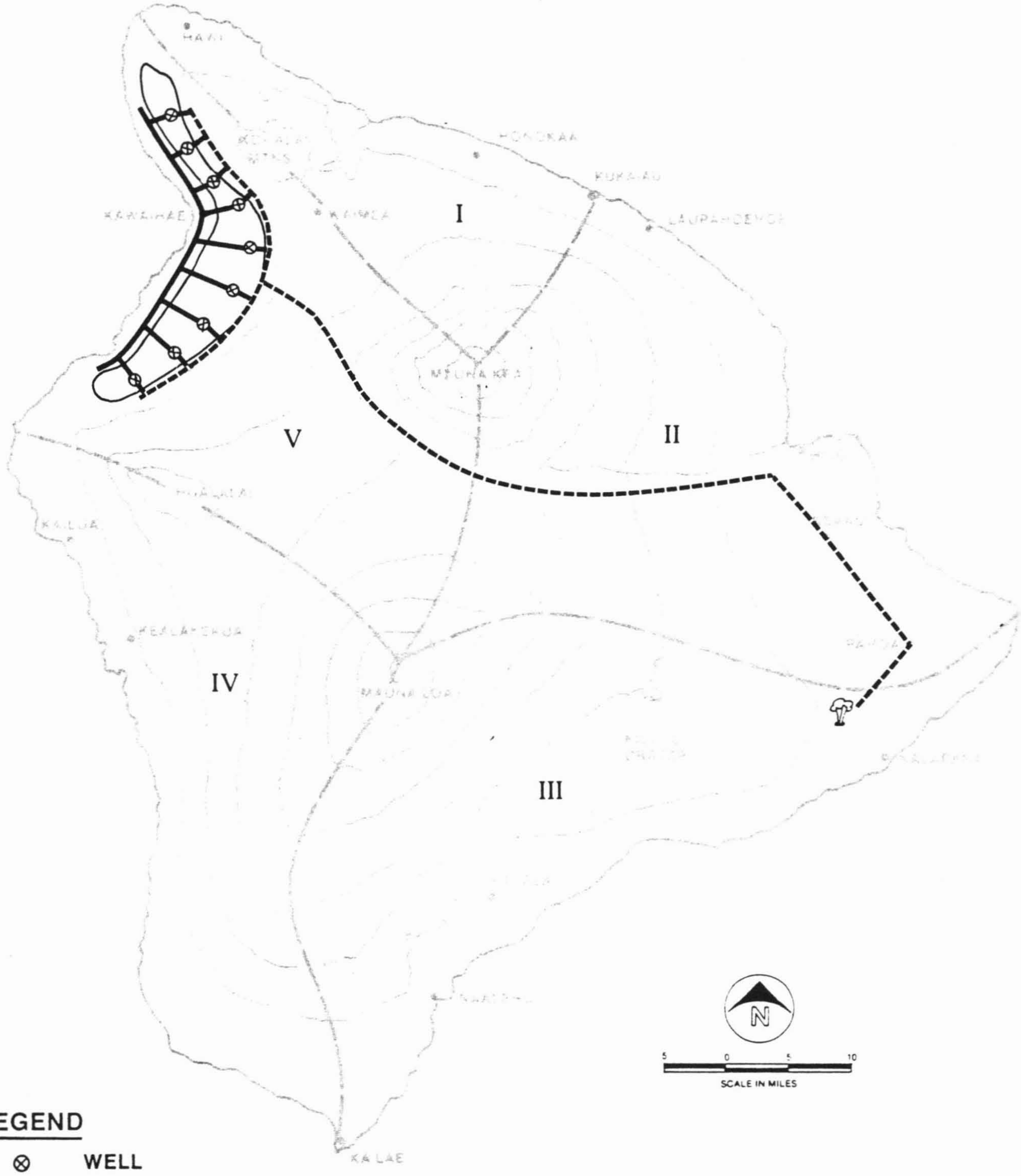


Figure 5.4
ALTERNATIVE W-4



LEGEND

⊗ WELL

● PUMP STATION

o HYDROELECTRIC PLANT

PIPELINE

CANAL

ELECTRICAL TRANSMISSION LINE

RESERVOIR

GEOTHERMAL PLANTS

Figure 5.5
ALTERNATIVE E-1

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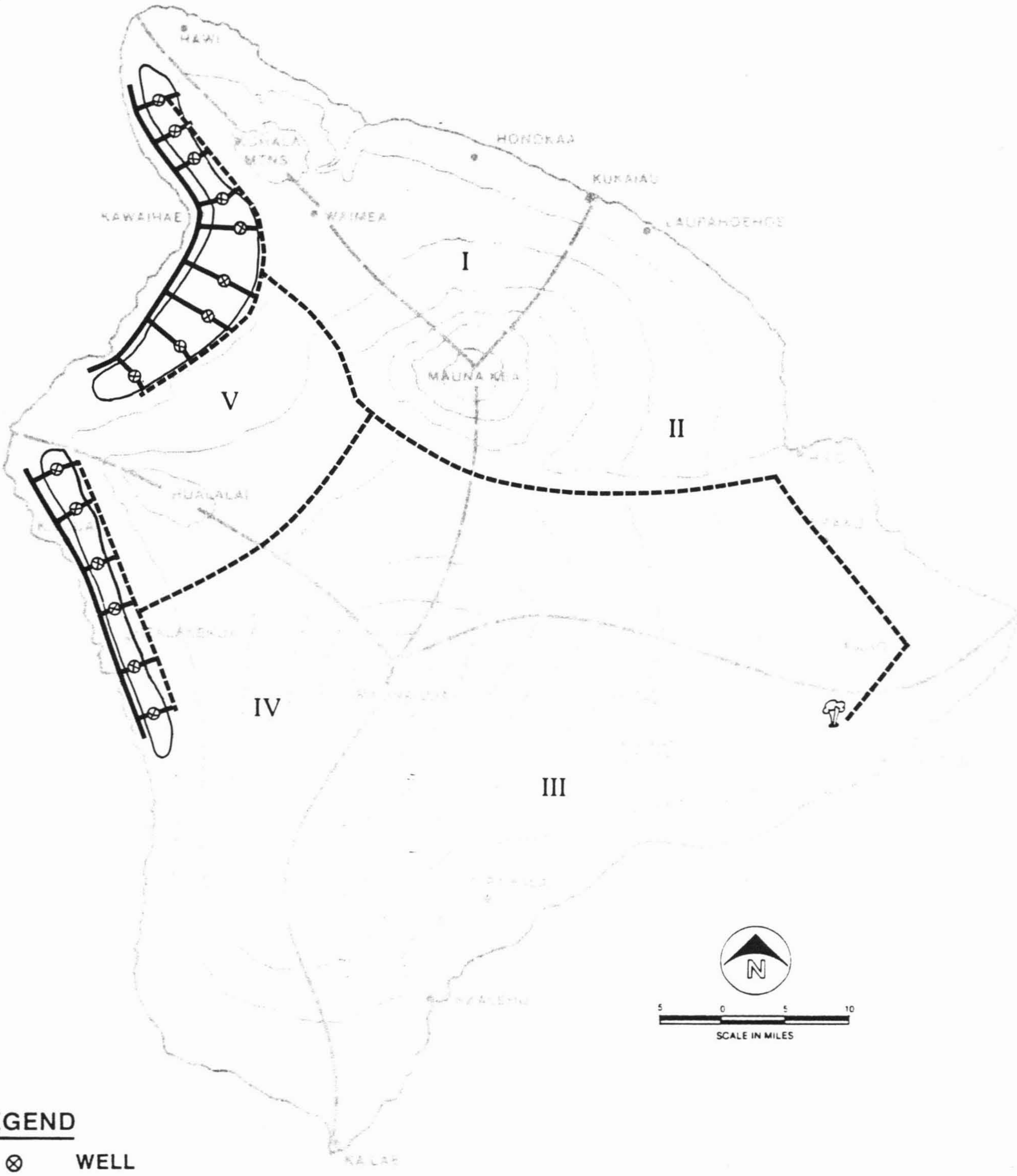


LEGEND

- ⊗ WELL
- ● PUMP STATION
- o HYDROELECTRIC PLANT
- PIPELINE
- CANAL
- ELECTRICAL TRANSMISSION LINE
- RESERVOIR
- GEOTHERMAL PLANTS

Figure 5.6
ALTERNATIVE E-2

CH2M HILL

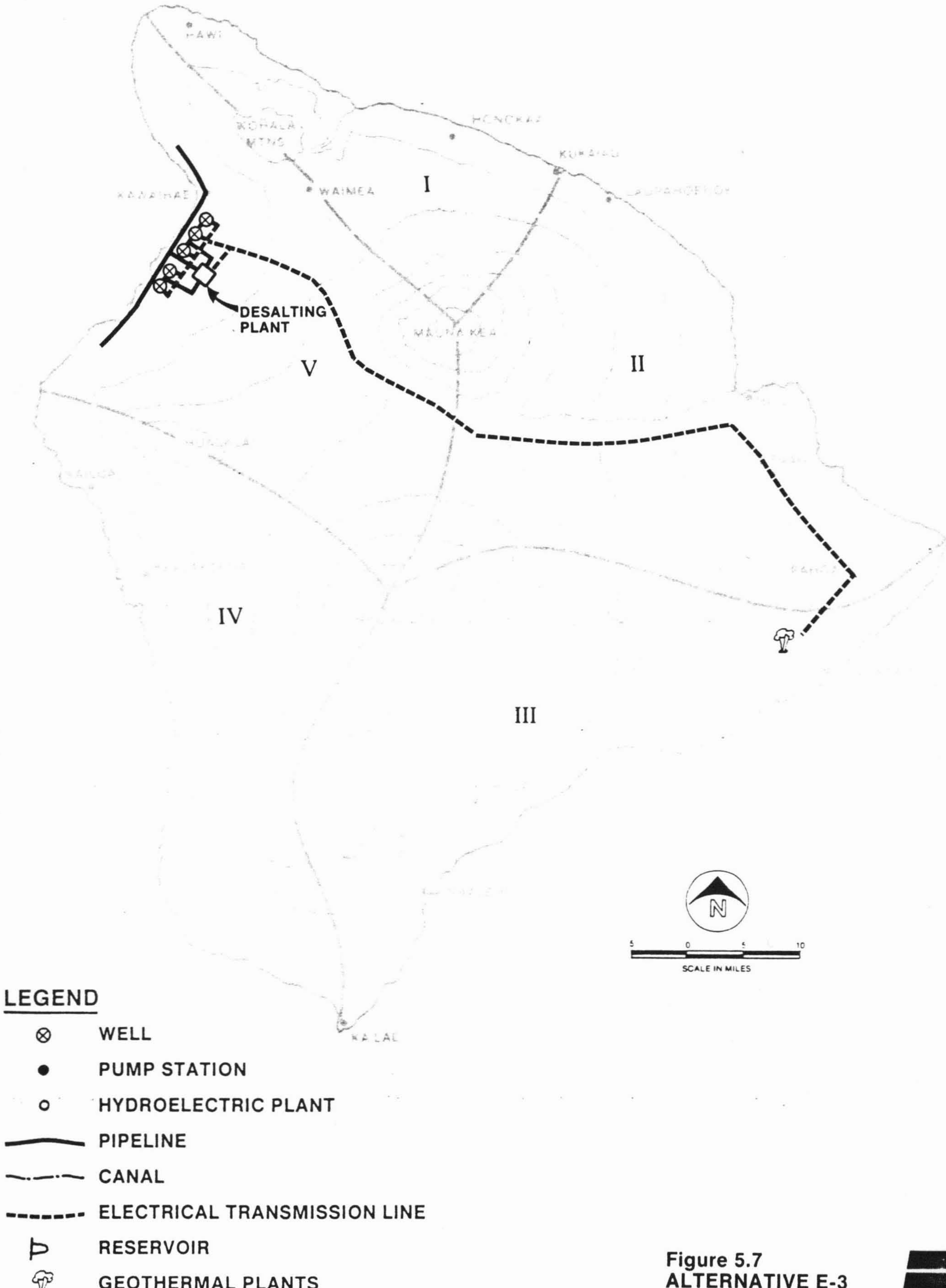


Figure 5.7
ALTERNATIVE E-3

CH2M HILL

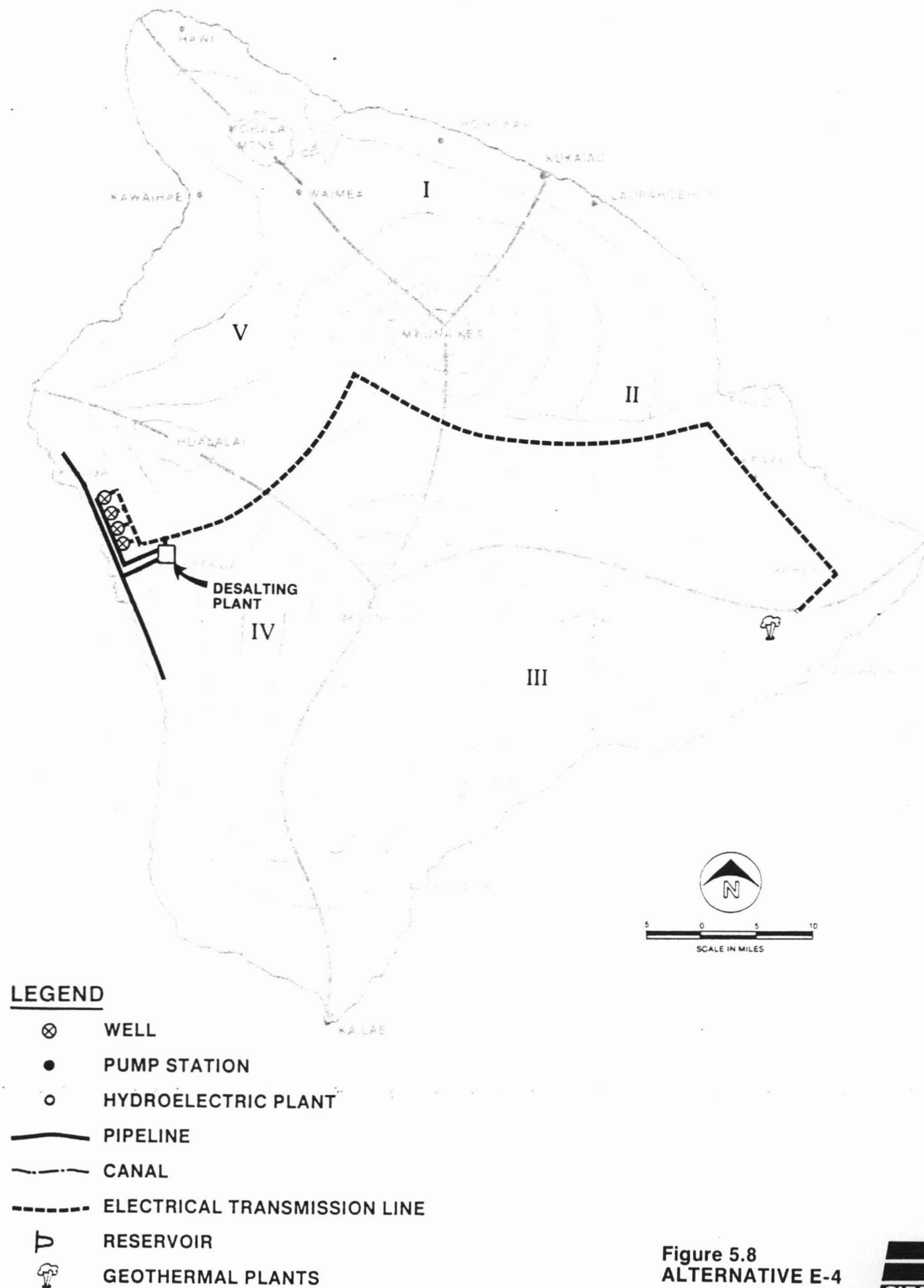
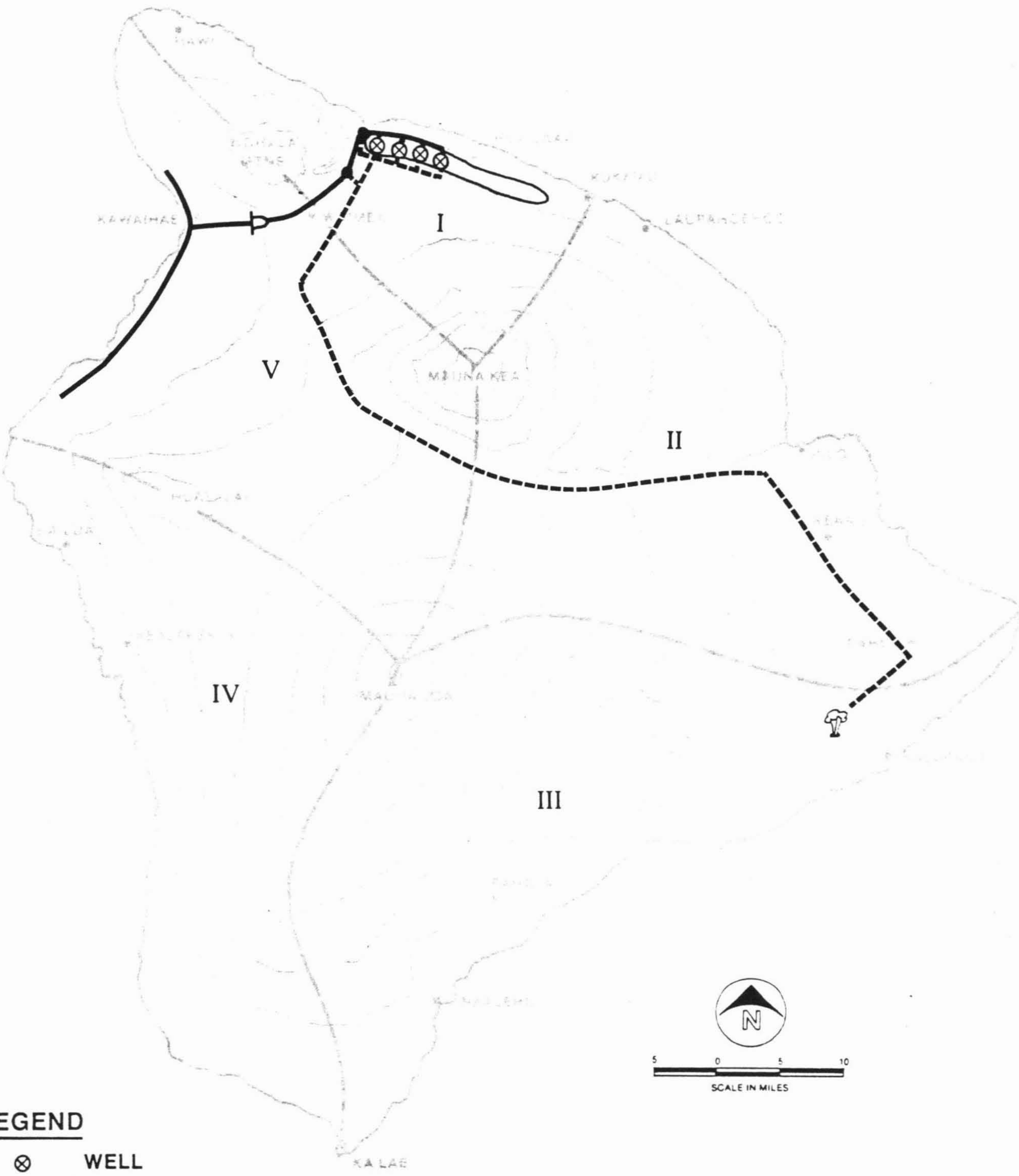


Figure 5.8
ALTERNATIVE E-4

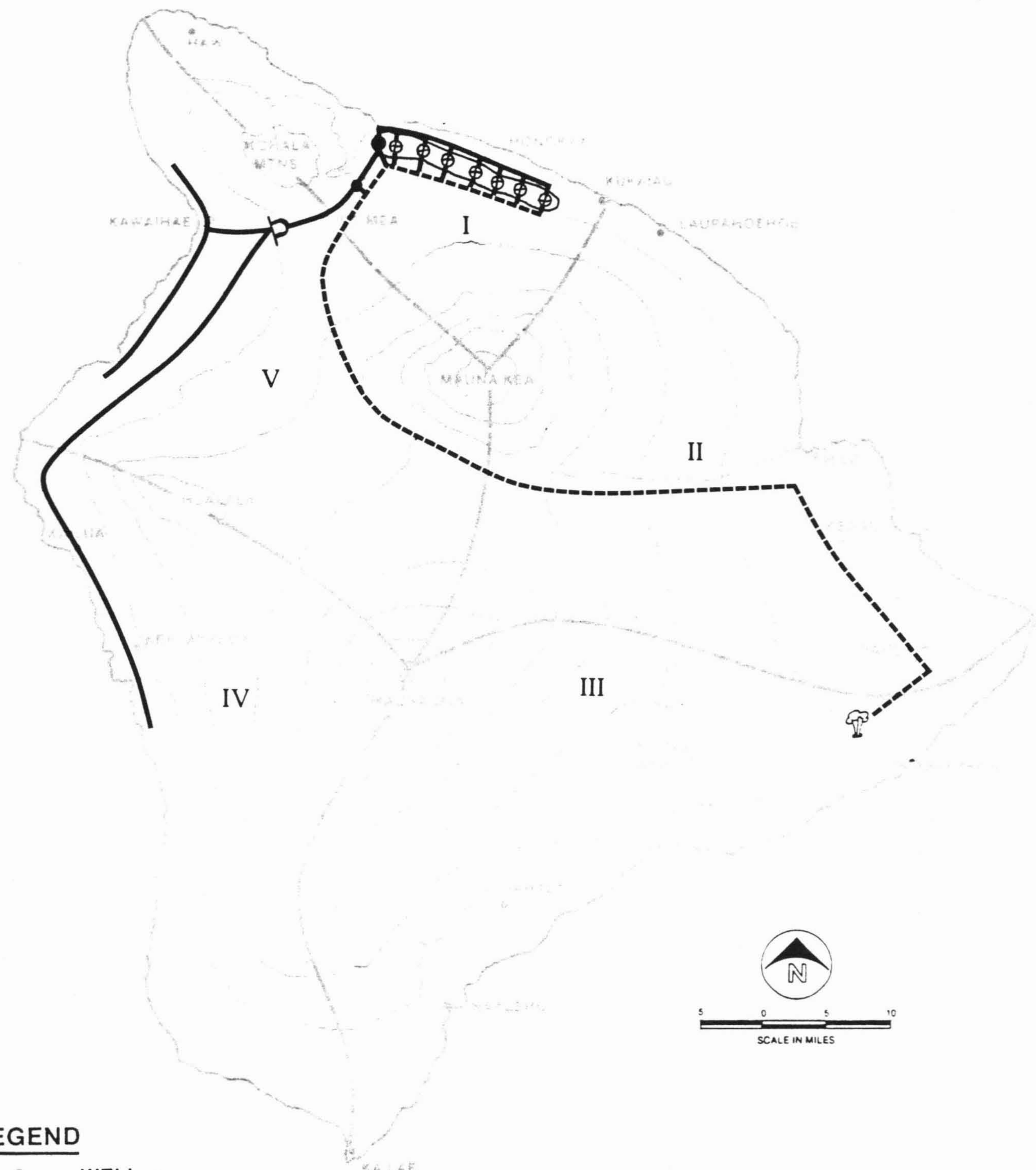
CH2M HILL



LEGEND

- ⊗ WELL
- ● PUMP STATION
- o HYDROELECTRIC PLANT
- PIPELINE
- CANAL
- ELECTRICAL TRANSMISSION LINE
- RESERVOIR
- GEOTHERMAL PLANTS

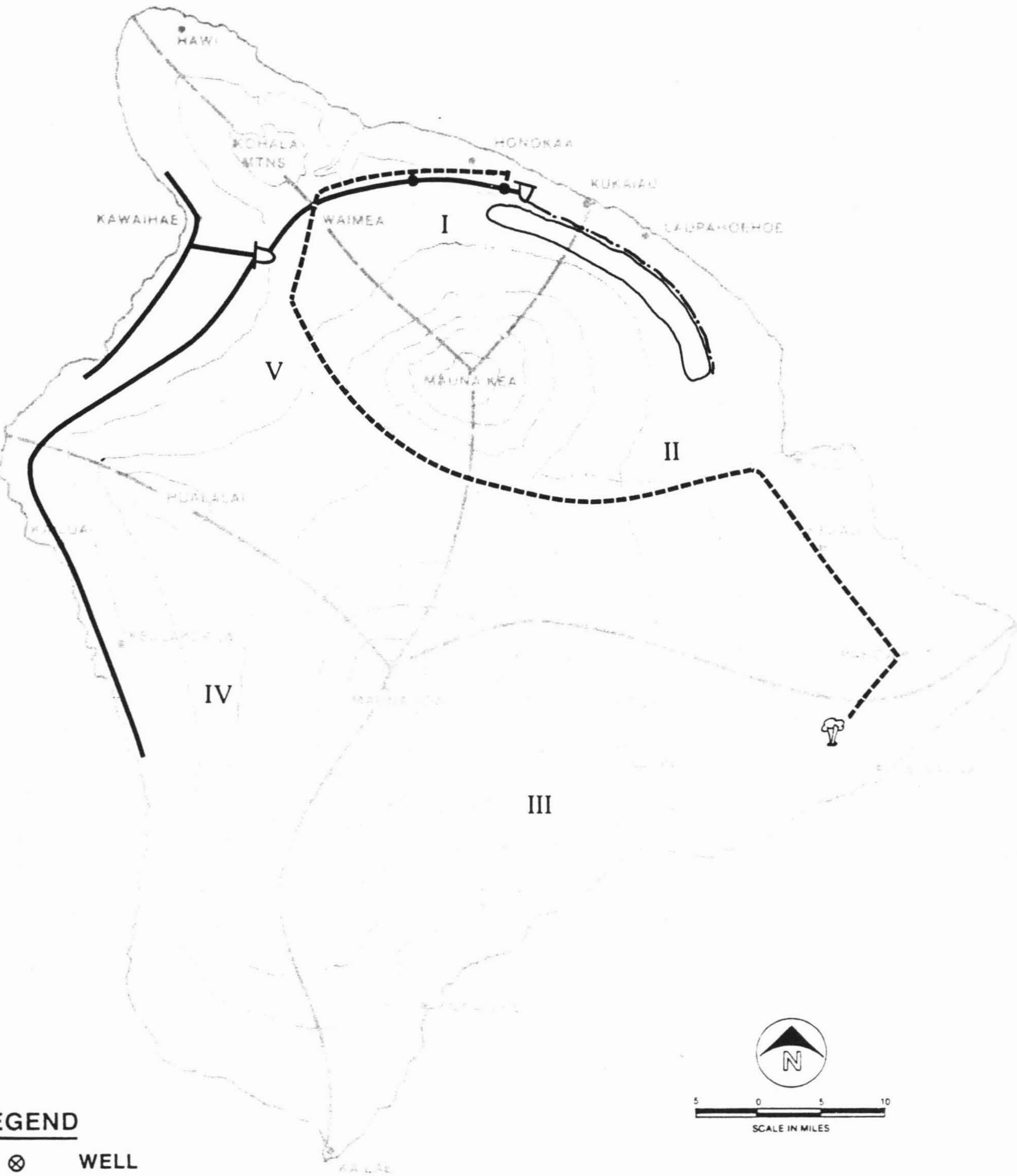
Figure 5.9
ALTERNATIVE EW-1



LEGEND

- ⊗ WELL
- ● PUMP STATION
- o HYDROELECTRIC PLANT
- ——— PIPELINE
- —·—·— CANAL
- - - - - - ELECTRICAL TRANSMISSION LINE
- RESERVOIR
- GEOTHERMAL PLANTS

Figure 5.10
ALTERNATIVE EW-2

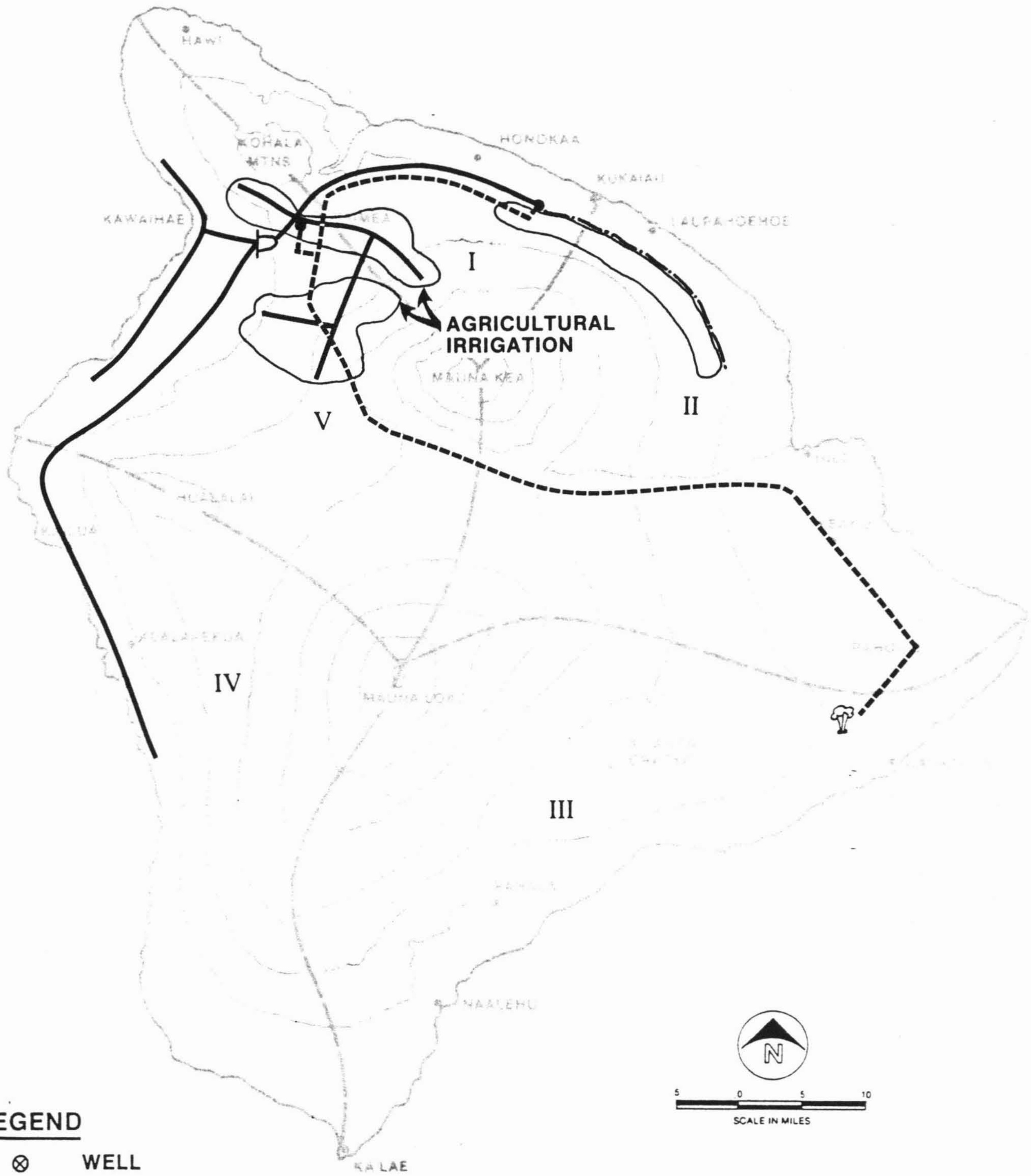


LEGEND

- ⊗ WELL
- ● PUMP STATION
- o HYDROELECTRIC PLANT
- PIPELINE
- CANAL
- ELECTRICAL TRANSMISSION LINE
- RESERVOIR
- GEOTHERMAL PLANTS

Figure 5.11
ALTERNATIVE EW-3

CH2M HILL



LEGEND

- ⊗ WELL
- ● PUMP STATION
- o HYDROELECTRIC PLANT
- ——— PIPELINE
- —·—·— CANAL
- ------- ELECTRICAL TRANSMISSION LINE
- RESERVOIR
- GEOTHERMAL PLANTS

Figure 5.12
ALTERNATIVE EW-4

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Section 6
CONCEPTUAL PLANS

Two projects were conceptually designed to show the range of costs, energy use, environmental effects, and institutional constraints of integrated water/energy development. The two projects generally correspond to Alternatives W-1 and E-1, as described in Section 5. The system capacities, however, were increased to a nominal 20 million gallons per day (mgd) to include water for agricultural use.

The projects are described in the following two subsections. The remaining subsections present an evaluation of the costs, energy system effects, and institutional and environmental issues and implications for other integrated water/renewable energy development opportunities.

6.1 PROJECT 1

Project 1 is like Alternative W-1. It would collect 20 mgd of water from the Wailuku River on the windward side of Hawaii and use excess off-peak geothermal energy to pump the water over the saddle for use on the leeward side of the island. Two suboptions to Project 1 were developed. Project 1A would use a smaller diameter pipeline on the leeward side of the saddle, which would use up most of the available head. Project 1B would use a larger diameter pipeline and would include hydroelectric facilities to generate energy. The Project 1 suboptions are shown in Figure 6.1.

6.1.1 PROJECT 1A

In this project, raw water will be taken from the Wailuku River at approximately the 3,000-foot elevation. The raw water will be treated by a 20-mgd water filtration plant located near the water intake. Treated water will be stored in a 20-million-gallon capacity covered prestressed concrete storage reservoir system at the treatment plant site. This storage is required because the water can be pumped over the saddle only during the off-peak energy demand period. A second storage facility will be located on the saddle between Mauna Loa and Mauna Kea, at elevation 6,600 feet. The treated water will be pumped from the treatment plant reservoir to the Saddle Reservoir by series of eight pump stations. These stations vary in size from 7,000 to 12,000 horsepower (hp). The water will be conveyed by a 42-inch-diameter, 17.3-mile-long pipeline aligned parallel to the Saddle Road (State Highway 200).

The 20-million-gallon Saddle Reservoir facility is also covered prestressed concrete construction. This storage system and location were selected because the water is

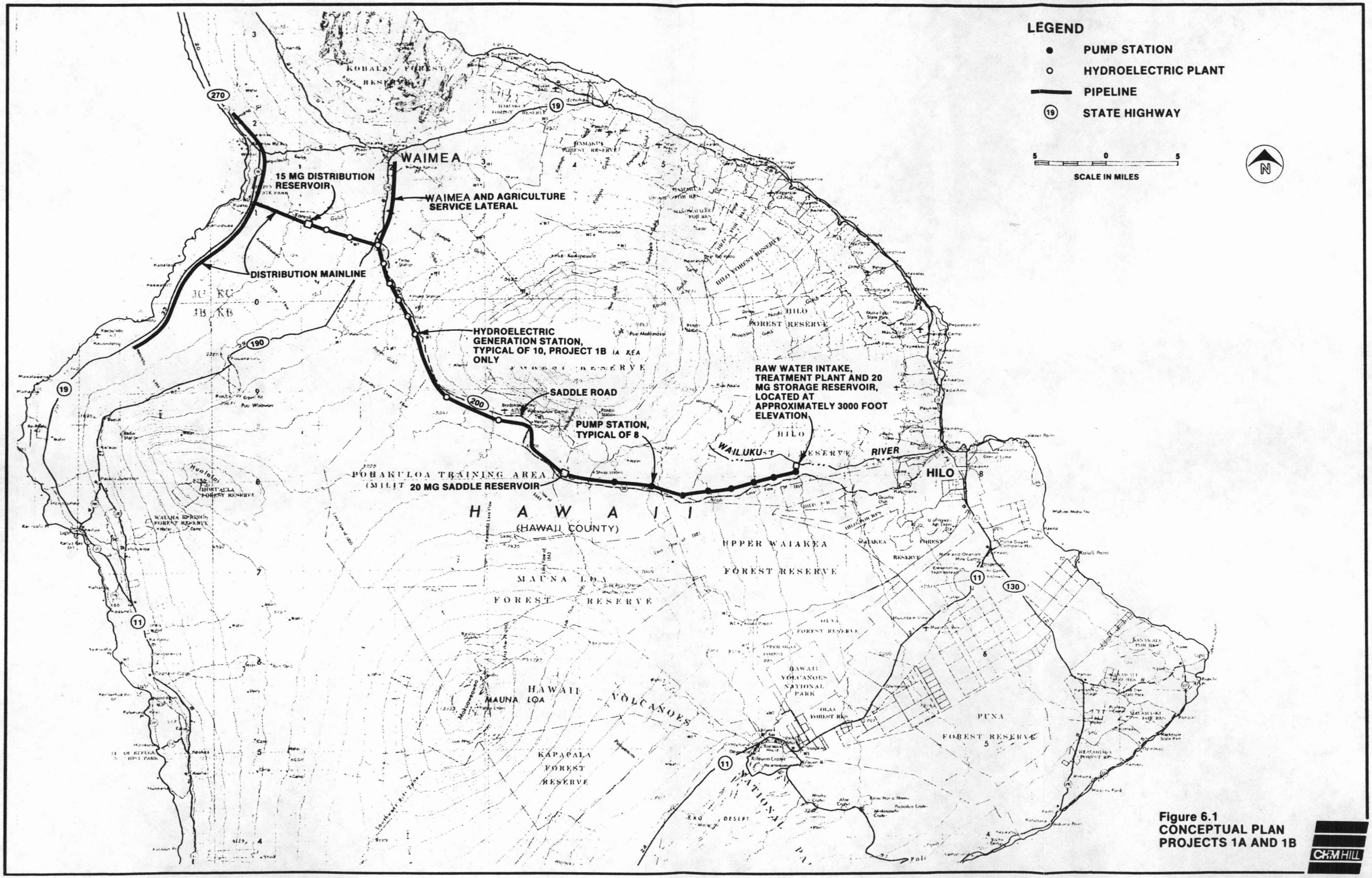

Figure 6.1
CONCEPTUAL PLAN
PROJECTS 1A AND 1B

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treated-potable water and some of the water may be used by the military base near the saddle. The Saddle Reservoir also provides flow equalization. The facility receives 20-million-gallons of water from the pump stations over a period of about 10 hours per day while delivering a constant outflow.

The water leaving the reservoir flows by gravity through a 29.5-mile-long pipeline along the Saddle Road to a 15-million-gallon capacity distribution reservoir located at elevation 1,300. This pipeline varies in size from 20- to 30-inch diameter and will use the available static head to deliver the water. No hydropower stations are provided in this suboption.

The Distribution Reservoir is sized to provide the needed volume of water for the diurnal water usage of a maximum day demand of 30 mgd while receiving uniform flow from the Saddle Reservoir. The Distribution Reservoir is also a covered, prestressed concrete structure. The 1,300-foot elevation was selected to allow adequate pressure to deliver the water by gravity to the water users along the island's northwest coast. Conceptual design and cost estimates for a 20- to 40-inch-diameter, 18.2-mile-long transmission pipeline along State Highway 19 are included to make the water delivery of Projects 1A and 1B equal to that provided in Project 2.

Project 1A will require electrical power transmission facilities to convey the energy from the geothermal development to the water treatment plant and the pump stations. It is assumed that the geothermal power will be interconnected to the island grid as part of the geothermal project facilities. It is also estimated that the existing 69 kV transmission line over the saddle, along with 138 kV system currently under construction, will be adequate to carry Project 1A power demands. No major new transmission lines are assumed to be necessary for the project. The cost of connecting the pump stations and water treatment plant to the HELCO grid is included in the cost estimates.

It is assumed that the overland portion of the proposed deep water cable would not be used in Project 1A. Problems with the local pump stations could expose the deep water cable system to shutdowns and thereby reduce the interisland transmission system's reliability.

6.1.2 PROJECT 1B

Project 1B is identical to 1A except for the pipeline between the saddle and distribution reservoirs. In Project 1B this pipeline will be 30 inches in diameter along its entire length to make the most of the static pressure head available for hydropower generation. Instead of using the head in frictional losses as in Project 1A, the hydroelectric plants convert the available head to electrical energy. There will be 10 hydrostations along the pipeline between the Saddle and Distribution Reservoirs that will vary in output from 725 to 1,050 kW.

The hydroelectric plant locations were selected to limit the pressure in the pipeline to less than 200 pounds per square inch. Because the flow in this pipeline will be uniform, the power generated by the hydroelectric plants will also be uniform.

Project 1B would require electrical transmission facilities for the hydroelectric power in addition to the supply facilities as described for the water treatment plant and pump stations in Project 1A. It is assumed that HELCO transmission systems would be used and that new transmission lines would not be required as part of the water/energy project. The cost of connecting the hydroelectric facilities to the HELCO grid is included in the cost estimates.

6.2 PROJECT 2

Project 2 is depicted in Figure 6.2. This project will use wells to serve the 20-mgd demand along the island's northwest coast. It is assumed that 20 wells, each with 1-mgd pumping capacity, will be located at approximately 1-mile intervals at elevation 1,300 feet. Each well will have a 2-million-gallon capacity storage tank at the well site and a chlorination facility. The power requirement of each well installation will be approximately 400 hp. The 2-million-gallon reservoir size was selected to provide emergency storage and flow equalization. The wells would be operated only during periods of available off-peak geothermal energy. Water from the individual wells would be fed to water users through local distribution facilities. These facilities are not included in the conceptual design or cost estimates.

It is assumed that the wells in Project 2 could be served by existing electrical power distribution systems. Therefore, only the costs of connecting the wells with the existing system are included in the conceptual plan.

6.3 COST AND ENERGY USE ESTIMATES

Tables 6.1, 6.2, and 6.3 present the estimated capital and annual operation and maintenance (O&M) costs for each of the projects. In Projects 1A and 1B, it is assumed that essentially all of the facilities will be built at the beginning of the project. Project 2 is assumed to be built in stages over 10 years to match the growth in water needs. The estimated annual energy use and generation are also shown for full scale, 20-mgd operation. Energy use and generation are

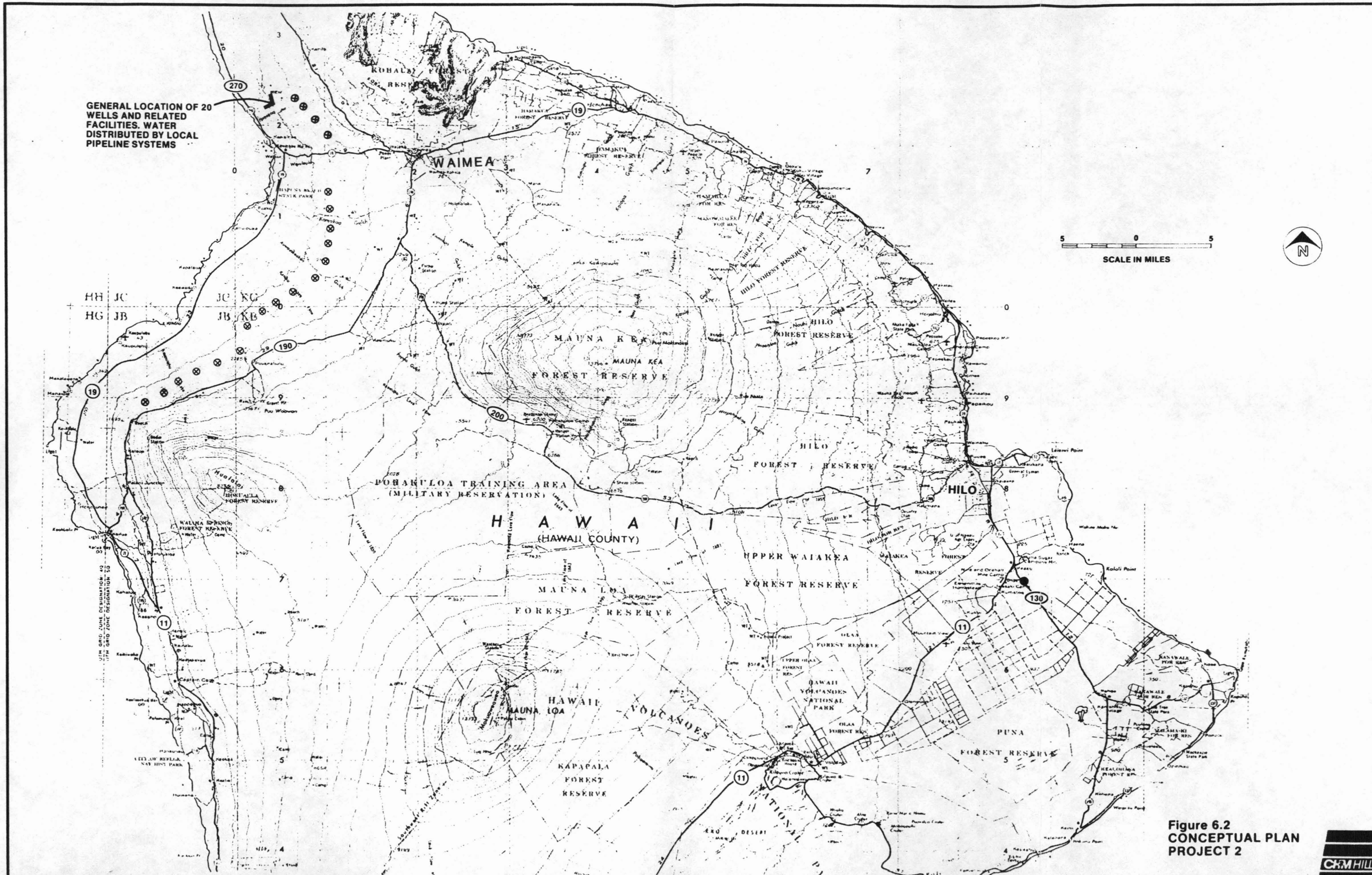

Figure 6.2
CONCEPTUAL PLAN
PROJECT 2

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Table 6.1
PROJECT 1A COSTS AND ENERGY ESTIMATES

Facilities	Capital Costs	Annual Energy[1] Use (Generation) (kWh/year)	Other Annual[1] O&M Costs (per year)
20-mgd water treatment plant including intake structure	$ 6,400,000	1,500,000	$ 190,000
20-million-gallon reservoir at WTP	7,000,000	--	35,000
8 pump stations, WTP to saddle reservoir	24,000,000	156,000,000	720,000
91,500-ft., 42-in. pipeline, WTP to saddle	29,200,000	--	145,000
20-million-gallon reservoir at saddle	7,000,000	--	35,000
156,000-ft., 20- to 30-in. pipeline, saddle to distribution reservoir	30,200,000	--	150,000
15-million-gallon distribution reservoir	5,800,000	--	30,000
96,000-ft., 30- to 42-in. distribution mainline	28,600,000	--	140,000
32,000-ft., 12-in. pipeline to Waimea and agricultural use	2,900,000	--	15,000
WTP and pump stations power interconnection	4,000,000	--	120,000
Totals	$145,000,000	158,000,000	$1,600,000

Total O&M Cost

At 3¢/kWh, energy cost = $4,700,000/yr, total O&M = $6,300,000/yr.
At 12¢/kWh, energy cost = $19,000,000/yr, total O&M = $20,600,000/yr.

[1]Annual costs and energy are for 20-mgd operation.

Table 6.2
PROJECT 1B COSTS AND ENERGY ESTIMATES

Facilities	Capital Costs	Annual Energy[1] Use (Generation) (kWh/year)	Other Annual[1] O&M Costs (per year)
20-mgd water treatment plant including intake structure	$ 6,400,000	1,500,000	$ 190,000
20-million-gallon reservoir at WTP	7,000,000	--	35,000
8 pump stations, WTP to saddle reservoir	24,000,000	156,000,000	720,000
91,500-ft., 42-in. pipeline, WTP to saddle	29,200,000	--	145,000
20-million-gallon reservoir at saddle	7,000,000	--	35,000
156,000-ft., 30-in. pipeline, saddle to distribution reservoir	35,600,000	--	180,000
10 hydropower plants	10,000,00	(83,000,000)	300,000
15-million-gallon distribution reservoir	5,800,000	--	30,000
96,000-ft., 30- to 42-in. distribution mainline	28,600,000	--	140,000
32,000-ft., 12-in. pipeline to Waimea and agricultural use	2,900,000	--	15,000
WTP and pump stations power interconnection	4,000,000	--	120,000
Hydropower interconnections	3,500,000	--	105,000
Totals	$164,000,000	75,000,000	$2,000,000

Total O&M Cost

At 3¢/kWh, energy cost = $2,300,000/yr, total O&M = $4,300,000/yr.
At 12¢/kWh, energy cost = $9,000,000/yr, total O&M = $11,000,000/yr.

[1]Annual costs and energy are for 20 mgd operation.

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Table 6.3
PROJECT 2 COSTS AND ENERGY ESTIMATES

Facilities	Capital Costs	Annual Energy[1] Use (Generation) (kWh/yr)	Other Annual[1] O&M Costs (per year)
20 1-mgd wells, with pumps and chlorination facilities	$20,000,000[2]	48,000,000	$600,000
20 2-million-gallon reservoirs	24,000,000	--	120,000
Well power interconnections	700,000[2]	--	21,000
Totals	$45,000,000	48,000,000	$740,000

Total O&M Cost

At 3¢/kWh, energy cost = $1,400,000/yr, total O&M = $2,100,000/yr.
At 12¢/kWh, energy cost = $5,800,000/yr, total O&M = $6,500,000/yr.

[1] Annual costs and energy are for 20-mgd operation.

[2] The well and reservoir construction are assumed to be staged over 10 years. The capital cost in each of the first 10 years will be 10 percent of these values.

assumed to increase to the full scale amounts over the first 10 years of operations.

Projects 1A and 1B have high capital costs of $145 million and $164 million, respectively. The major cost items are the pump stations and transmission pipelines, which account for about 70 percent of the total cost. The capital cost of Project 2 is about $45 million. This cost would be incurred over 10 years.

Total annual costs vary depending on the assumed energy cost and value. A range of 3 to 12 cents/kWh was used in the analysis, as discussed in Section 4.4.3. It is assumed that the value of generated hydroelectric energy would be the same as the cost of energy used in pumping water.

In Project 1A, annual energy costs are expected to be $4.7 million at 3 cents/kWh and to $19 million at 12 cents. The other annual O&M costs, which include equipment repair and maintenance and operation labor and materials, total about $1.6 million for Project 1A. The total O&M costs are $6.3 million per year at 3 cents/kWh and $20.6 million per year at 12 cents/kWh. The total O&M costs are about 3.3 times higher with the higher energy cost.

Project 1B has lower annual energy costs because of the credit from hydroelectric generation. Hydroelectric generation replaces about half of the energy used in pumping the water to the top of the saddle. The annual energy cost is $2.3 million at 3 cents/kWh and $9 million at 12 cents/kWh. The other O&M costs are somewhat higher than for Project 1A because of the addition of the hydroelectric plants. The total O&M costs are $4.3 million per year at 3 cents/kWh and $11.0 million per year at 12 cents/kWh. The total O&M costs are about 2.6 times higher with the higher energy cost.

The energy used in Project 2 is estimated to cost $1.4 million per year at 3 cents/kWh and $5.8 million per year at 12 cents/kWh. The other O&M costs total about $740,000 per year. The total O&M costs are estimated to be $2.1 million and $6.5 million, respectively, for 3 cents/kWh and 12 cents/kWh. The total O&M costs are 3.1 times higher with the higher energy cost.

The cost of the water developed by the integrated water/energy projects is presented in Table 6.4. The water costs were developed assuming a 50-year project life, no inflation, 10 percent interest rate, and no salvage value. The capital and O&M costs presented in Tables 6.1 through 6.3 were used in the analysis. These costs were staged as appropriate during the first 10 years. It was also assumed that major mechanical equipment would be replaced in the 25th year. Appendix A presents detailed breakdowns of the yearly costs. The present worth and total annualized costs are also presented. The average annualized present worth costs were divided by the average annual water supply to compute the water cost.

As shown in Table 6.4, the water costs with Projects 1A and 1B range from $2.79 to $4.59 per thousand gallons. The water costs for Project 2 are much lower at $0.71 to $1.20 per thousand gallons. The addition of hydroelectric power generation, Project 1B, increases the water cost by $0.30 per thousand gallons when the energy value is low at 3 cents/kWh. When the energy value is higher, at 12 cents/kWh, Project 1B reduces the water cost by $0.76/kWh.

The following conclusions are apparent from analysis of the water costs:

- o Project 2, with its lower capital costs, has much lower water costs than Projects 1A and 1B.
- o Including hydroelectric power generation in Project 1 is not beneficial at 3 cents/kWh but is beneficial at 12 cents/kWh.
- o The cost of water in Project 2 at an energy cost of 3 cents/kWh is slightly less than current Department of Water supply costs (current costs are $0.89 to $1.04 per thousand gallons, depending on rate of consumption).
- o The energy cost at which the water cost is $1.00 per thousand gallons is about 8.5 cents/kWh.

The cost estimates presented herein are in terms of late-1986 dollars. They include nominal contingencies but do not include engineering, overhead, or permitting costs. They also do not include the cost of developing geothermal energy or the total cost of distributing the water to individual users.

The estimates are order-of-magnitude estimates as categorized by the American Association of Cost Engineers. Order-of-magnitude estimates are approximate estimates made without detailed engineering data or drawings. Examples would include an estimate from cost capacity curves, an estimate using scale-up or scale-down factors, and an approximate ratio estimate. It is normally expected that an estimate of this type would be accurate within +50 percent and -30 percent.

The cost estimates shown, and any resulting conclusions on project financial, economic feasibility, or funding requirements, have been prepared for guidance in project evaluation

Table 6.4
WATER COSTS

Project	Energy Cost	Water Cost
1A	3¢/kWh	$2.79/1,000 gal.
1A	12¢/kWh	$4.59/1,000 gal.
1B	3¢/kWh	$3.09/1,000 gal.
1B	12¢/kWh	$3.83/1,000 gal.
2	3¢/kWh	$0.71/1,000 gal.
2	12¢/kWh	$1.20/1,000 gal.

and implementation from the information available at the time the estimates were prepared. The final costs of the project and resulting feasibility will depend on actual labor and material costs, competitive market conditions, actual site conditions, final project scope, implementation schedule, continuity of personnel and engineering, and other variable factors. As a result, the final project costs will vary from the estimates of costs presented herein. Because of these factors project feasibility, benefit/cost ratios, risks, and funding needs must be carefully reviewed before making specific financial decisions or establishing project budgets to help ensure proper project evaluation and adequate funding.

6.4 ENERGY SUPPLY CONSIDERATIONS

Project 1A would use about 158 million kWh or 158,000 MWh per year. The peak demand would be about 61 MW. Project 1B would use the same amount of energy for pumping and treatment as Project 1A, but would generate about 83,000 MWh per year. The net energy use would be about 75,000 MWh per year. The average hydroelectric generation capacity would be about 10 MW. Project 2 will use 48,000 MWh per year for well pump operation. The power demand for supplying 20 mgd will be about 6 MW.

Since Project 1 requires about 61 MW to operate the pumps, the 50-MW geothermal project, as described in Section 4.4.2, would be inadequate to supply 20 mgd as envisioned in Project 1. Only about 35 MW of excess power is available with the 50-MW geothermal project. Therefore, a water energy project like Project 1 would be limited to about 11 mgd capacity. With a 500-MW geothermal project, adequate power is available for a 20-mgd or larger water energy project.

Also, as discussed in Section 4.4.2, the amount of energy available for a 50-MW geothermal project is 120,000 MWh per year, and 1,000,000 MWh per year for a 500-MW geothermal project. Project 1A would consume 158,000 MWh per year and, therefore, would not be feasible with just a 50-MW geothermal project. It would be feasible with a larger geothermal project. Project 1B consumes a net 75,000 MWh per year and Project 2 consumes 48,000 MWh per year. Therefore, these two water/energy projects would be feasible with the smaller geothermal project.

Including hydroelectric power generation in Project 1B is a form of pumped storage and, in effect, a method of converting excess off-peak power for 24-hour-per-day use. Pumped storage projects are typically used to store available off-peak power for use during peak demand periods. Project 1B could also be configured to provide this operation. This would, however, require an increase in pipeline and hydroelectric plant sizes and would increase capital costs.

6.5 INSTITUTIONAL AND ENVIRONMENTAL CONSIDERATIONS

The two conceptual plans raise several institutional and environmental issues for consideration. Institutional issues include water rights and water transfer, land acquisition requirements, construction financing, acquisition of excess energy, energy cost and value, permitting requirements, and local public acceptance. Environmental issues include construction impacts, operating impacts, and secondary impacts related to economic growth.

6.5.1 INSTITUTIONAL

Projects 1A and 1B involve the transfer of a large quantity of Wailuku River water to the leeward side of the island. This proposal is likely to concern the City of Hilo and other domestic and agricultural water users who rely on the river for their water supply. Additional hydrologic studies would be required to verify the availability of the quantity of water to be transferred and to determine the effects on existing water users. Additional engineering and environmental study is also needed to select the point of diversion.

Project 2 expands the existing practice of using wells to collect potable water for use in the nearby area. Therefore, water transfer will not be a major concern. Hydrologic studies are needed, however, to better determine the safe extraction rate. The feasibility of drilling and operating deeper wells, located at higher elevations farther from the coastline, also needs to be confirmed by test drilling programs.

The various facilities and approximately 50 miles of pipeline required for Projects 1A and 1B will require construction on many parcels of public and privately-held lands. Obtaining easements and rights-of-way could be time consuming and costly because of the potentially large number of landowners involved. The Saddle Road route that was proposed in the conceptual plan would use existing rights-of-way where feasible, thereby lessening land acquisition requirements.

Project 2 has minimal land requirements for the wells and related water storage tanks; therefore, land acquisition should not be a major issue.

Projects 1A and 1B have large financial requirements. Initial construction costs are estimated to be over $150 million. This scale of project is probably beyond the funding capacity of Hawaii County agencies. State and possibly federal level financing would be required.

Project 2 has lower construction costs and the costs can be staged over several years. Therefore, financing is not a major constraint. Several wells like those proposed for Project 2 have already been financed and installed and are in use.

The integrated water/energy projects suggested in Section 5 would use excess off-peak geothermal energy. Availability of this energy is not certain at this time. Ongoing studies of the feasibility of cycling the geothermal wells and generators may show that full cycling to match diurnal needs is possible. This would reduce the energy excess. There may also be competing demands for the excess energy. In addition, the method of acquiring excess energy for a water/energy project needs to be resolved. Options include direct purchase from the geothermal developer(s) and purchase and transmission through HELCO. If the large geothermal project with the deep water cable becomes a reality, the Maui and Oahu electric utilities would also enter the picture in resolving how excess energy would be used.

As discussed in Section 4.4.3, the cost of excess geothermal energy for use in a water/energy project is also uncertain. It can be argued that since the energy is "excess" it has little related cost and should therefore be available for a lower cost than conventional energy supplies. On the other hand, geothermal developers will be looking for the highest income possible. It might also be said that all electric energy users on the island should benefit equally by the use of excess energy and the benefits should not accrue just to water users on the dry side of the island. This issue is clearly a complicated one and cannot be answered within the scope of this study. In any event, making use of the excess energy will enhance the feasibility of geothermal development and should be encouraged. This issue is generally the same regardless of what type of water/energy project is developed.

Projects 1A and 1B would entail major permitting requirements because of the water rights and water transfer issues, relatively large land requirements, and the extensive facilities required to collect, treat, store, and transport the water. Project 2 would have considerably fewer permitting requirements, generally limited to well installation requirements.

Concern has been voiced by residents of the island of Hawaii that the deep water cable project and its related large geothermal development will have little local benefit. The benefits would be realized mainly on Oahu and Maui, where the energy is to be used, while all the potential adverse environmental effects will be felt on Hawaii. Projects 1 and 2 have the opportunity of providing significant benefit on the Big Island in the form of providing water for economic development.

6.5.2 ENVIRONMENTAL

Projects 1A and 1B would have major environmental impacts related to construction. Construction activities would include building a raw water intake and diversion structure on the Wailuku River, building the water treatment plant, building eight pump stations, building ten hydroelectric plants, building three storage reservoirs, and constructing 50 miles of pipeline. This work would generally be limited to the Saddle Road and other developed areas. However, some conservation areas may be affected depending on the pipeline routing and the diversion point on the Wailuku River.

Project 2 construction activities would include drilling of about 20 wells and building of storage tanks, access roads, and power lines. These activities may have significant local impacts on small areas, but the overall magnitude would be much smaller than for Projects 1A or 1B.

The environmental impacts of operating Project 1A include reduced flow in the Wailuku River below the diversion point, waste disposal from the water treatment plant operations, pump station and water treatment plant noises and visual impacts, and the visual impact of power lines. Project 1B has the additional noise and visual impacts related to the hydroelectric power plants. Project 2 operating impacts include use of the potable groundwater supply and noise and visual impacts of the numerous well pumps and related facilities.

A secondary impact of using off-peak energy is the potential benefit to the operation of the geothermal facilities. If off-peak geothermal energy can be used in a water/energy project, the need to bleed off steam to the atmosphere during off-peak periods would be reduced.

Section 2 showed the need for water for expanding development on the west coast of Hawaii. The water/energy projects described in this section will allow that development to occur. Therefore, the water/energy projects create the opportunity for economic growth to occur. This growth will have significant secondary impacts on the environment of the island.

6.6 SUMMARY AND IMPLICATIONS FOR OTHER PROJECTS

Project 2 is similar to the existing method of developing groundwater in Hydrographic Area V (South Kohala District) with the following exceptions: (1) a special cost rate must be negotiated for the use of the excess energy; (2) the use of the lower cost energy allows economical high pump lifts; (3) the wells can be located farther inland and away from brackish waters; and (4) storage is required to equalize off-peak well pumping with water demands.

Project 1 would probably require the completion of the deep water cable and the large geothermal project to have adequate energy to move a large quantity of water. Project 2, on the other hand, could be developed without the deep water cable and the larger geothermal project.

Projects 1A and 1B have major institutional, environmental, and economic constraints and do not appear feasible for development. On the other hand, Project 2 appears quite feasible for development.

Much of what has been learned from the analysis of Projects 1 and 2 can be applied in considering other potential integrated water/renewable energy resource projects throughout the state. High capital cost projects may not be feasible even with low cost renewable energy. Water projects with low capital costs and high energy needs have the greatest potential of becoming feasible by integration with renewable energy projects. Available off-peak energy can be used to develop water resources. Geothermal development can be enhanced through the use of excess off-peak energy for water resources development.

Section 7
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Appendix

Table A.1
Project 1A Costs with $0.03/kWh Energy

Year	Capital Cost	Annual Energy Cost	Other Annual O&M Costs	Total Annual O&M Costs	Total Costs	Discount Factor (i = 10%)	Present Worth Cost
1	$145,000,000	$470,000	$1,600,000	$2,070,000	$147,070,000	1.0000	$133,700,000
2	---	$940,000	$1,600,000	$2,540,000	$2,540,000	0.9091	$2,099,174
3	---	$1,410,000	$1,600,000	$3,010,000	$3,010,000	0.8264	$2,487,603
4	---	$1,880,000	$1,600,000	$3,480,000	$3,480,000	0.7513	$2,614,576
5	---	$2,350,000	$1,600,000	$3,950,000	$3,950,000	0.6830	$2,697,903
6	---	$2,820,000	$1,600,000	$4,420,000	$4,420,000	0.6209	$2,744,472
7	---	$3,290,000	$1,600,000	$4,890,000	$4,890,000	0.5645	$2,760,278
8	---	$3,760,000	$1,600,000	$5,360,000	$5,360,000	0.5132	$2,750,528
9	---	$4,230,000	$1,600,000	$5,830,000	$5,830,000	0.4665	$2,719,738
10	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.4241	$2,671,815
11	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.3855	$2,428,923
12	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.3505	$2,208,112
13	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.3186	$2,007,374
14	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.2897	$1,824,886
15	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.2633	$1,658,987
16	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.2394	$1,508,170
17	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.2176	$1,371,064
18	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.1978	$1,246,421
19	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.1799	$1,133,110
20	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.1635	$1,030,100
21	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.1486	$936,455
22	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.1351	$851,323
23	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.1228	$773,930
24	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.1117	$703,572
25	$6,960,000	$4,700,000	$1,600,000	$6,300,000	$13,260,000	0.1015	$1,346,229
26	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0923	$581,465
27	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0839	$528,604
28	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0763	$480,549
29	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0693	$436,863
30	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0630	$397,148
31	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0573	$361,044
32	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0521	$328,222
33	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0474	$298,383
34	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0431	$271,258
35	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0391	$246,598
36	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0356	$224,180
37	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0323	$203,800
38	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0294	$185,273
39	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0267	$168,430
40	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0243	$153,118
41	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0221	$139,198
42	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0201	$126,544
43	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0183	$115,040
44	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0166	$104,582
45	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0151	$95,074
46	---	$4,700,000	$1,600,000	$6,300.000	$6,300,000	0.0137	$86,431
47	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0125	$78,574
48	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0113	$71,431
49	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0103	$64,937
50	---	$4,700,000	$1,600,000	$6,300,000	$6,300,000	0.0094	$59,034
Total	$151,960,000	$213,850,000	$80,000,000	$293,850,000	$445,810,000		$184,080,518

Annualized Cost = $18,566,177

Cost per 1,000 gal delivered = $2.7948

Table A.2
Project 1A Costs with $0.12/kWh Energy

Year	Capital Cost	Annual Energy Cost	Other Annual O&M Costs	Total Annual O&M Costs	Total Costs	Discount Factor (i = 10%)	Present Worth Cost
1	$145,000,000	$1,900,000	$1,600,000	$3,500,000	$148,500,000	1.0000	$148,500,000
2	---	$3,800,000	$1,600,000	$5,400,000	$5,400,000	0.9091	$4,909,091
3	---	$5,700,000	$1,600,000	$7,300,000	$7,300,000	0.8264	$6,033,058
4	---	$7,600,000	$1,600,000	$9,200,000	$9,200,000	0.7513	$6,912,096
5	---	$9,500,000	$1,600,000	$11,100,000	$11,100,000	0.6830	$7,581,449
6	---	$11,400,000	$1,600,000	$13,000,000	$13,000,000	0.6209	$8,071,977
7	---	$13,300,000	$1,600,000	$14,900,000	$14,900,000	0.5645	$8,410,662
8	---	$15,200,000	$1,600,000	$16,800,000	$16,800,000	0.5132	$8,621,056
9	---	$17,100,000	$1,600,000	$18,700,000	$18,700,000	0.4665	$8,723,688
10	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.4241	$8,736,411
11	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.3855	$7,942,192
12	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.3505	$7,220,174
13	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.3186	$6,563,795
14	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.2897	$5,967,086
15	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.2633	$5,424,624
16	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.2394	$4,931,476
17	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.2176	$4,483,160
18	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.1978	$4,075,600
19	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.1799	$3,705,091
20	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.1635	$3,368,265
21	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.1486	$3,062,059
22	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.1351	$2,783,690
23	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.1228	$2,530,627
24	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.1117	$2,300,570
25	$6,960,000	$19,000,000	$1,600,000	$20,600,000	$27,560,000	0.1015	$2,798,045
26	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0923	$1,901,298
27	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0839	$1,728,452
28	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0763	$1,571,320
29	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0693	$1,428,473
30	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0630	$1,298,612
31	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0573	$1,180,556
32	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0521	$1,073,233
33	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0474	$975,666
34	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0431	$886,969
35	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0391	$806,336
36	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0356	$733,033
37	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0323	$666,393
38	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0294	$605,812
39	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0267	$550,738
40	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0243	$500,671
41	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0221	$455,156
42	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0201	$413,778
43	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0183	$376,162
44	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0166	$341,965
45	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0151	$310,877
46	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0137	$282,616
47	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0125	$256,923
48	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0113	$233,567
49	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0103	$212,333
50	---	$19,000,000	$1,600,000	$20,600,000	$20,600,000	0.0094	$193,030
Total	$151,960,000	$864,500,000	$80,000,000	$944,500,000	$1,096,460,000		$302,639,912

Annualized Cost = $30,523,959

Cost per 1,000 gal delivered = $4.5949

Table A.3
Project 1B Costs with $0.03/kWh Energy

Year	Capital Cost	Annual Energy Cost	Other Annual O&M Costs	Total Annual O&M Costs	Total Costs	Discount Factor (i = 10%)	Present Worth Cost
1	$164,000,000	$230,000	$2,000,000	$2,230,000	$166,230,000	1.0000	$166,230,000
2	---	$460,000	$2,000,000	$2,460,000	$2,460,000	0.9091	$2,236,364
3	---	$690,000	$2,000,000	$2,690,000	$2,690,000	0.8264	$2,223,140
4	---	$920,000	$2,000,000	$2,920,000	$2,920,000	0.7513	$2,193,839
5	---	$1,150,000	$2,000,000	$3,150,000	$3,150,000	0.6830	$2,151,492
6	---	$1,380,000	$2,000,000	$3,380,000	$3,380,000	0.6209	$2,098,714
7	---	$1,610,000	$2,000,000	$3,610,000	$3,610,000	0.5645	$2,037,751
8	---	$1,840,000	$2,000,000	$3,840,000	$3,840,000	0.5132	$1,970,527
9	---	$2,070,000	$2,000,000	$4,070,000	$4,070,000	0.4665	$1,898,685
10	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.4241	$1,823,620
11	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.3855	$1,657,836
12	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.3505	$1,507,124
13	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.3186	$1,370,113
14	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.2897	$1,245,557
15	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.2633	$1,132,324
16	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.2394	$1,029,386
17	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.2176	$935,805
18	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.1978	$850,732
19	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.1799	$773,393
20	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.1635	$703,084
21	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.1486	$639,168
22	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.1351	$581,061
23	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.1228	$528,238
24	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.1117	$480,216
25	$9,460,000	$2,300,000	$2,000,000	$4,300,000	$13,760,000	0.1015	$1,396,992
26	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0923	$396,873
27	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0839	$360,793
28	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0763	$327,994
29	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0693	$298,176
30	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0630	$271,069
31	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0573	$246,427
32	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0521	$224,024
33	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0474	$203,658
34	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0431	$185,144
35	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0391	$168,313
36	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0356	$153,012
37	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0323	$139,101
38	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0294	$126,456
39	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0267	$114,960
40	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0243	$104,509
41	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0221	$95,008
42	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0201	$86,371
43	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0183	$78,519
44	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0166	$71,381
45	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0151	$64,892
46	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0137	$58,993
47	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0125	$53,630
48	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0113	$48,754
49	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0103	$44,322
50	---	$2,300,000	$2,000,000	$4,300,000	$4,300,000	0.0094	$40,293
Total	$173,460,000	$104,650,000	$100,000,000	$204,650,000	$378,110,000		$203,657,835

Annualized Cost = $20,540,726

Cost per 1,000 gal delivered = $3.0921

Table A.4
Project 1B Costs with $0.12/kWh Energy

Year	Capital Cost	Annual Energy Cost	Other Annual O&M Costs	Total Annual O&M Costs	Total Costs	Discount Factor (i = 10%)	Present Worth Cost
1	$164,000,000	$900,000	$2,000,000	$2,900,000	$166,900,000	1.0000	$166,900,000
2	---	$1,800,000	$2,000,000	$3,800,000	$3,800,000	0.9091	$3,454,545
3	---	$2,700,000	$2,000,000	$4,700,000	$4,700,000	0.8264	$3,884,298
4	---	$3,600,000	$2,000,000	$5,600,000	$5,600,000	0.7513	$4,207,363
5	---	$4,500,000	$2,000,000	$6,500,000	$6,500,000	0.6830	$4,439,587
6	---	$5,400,000	$2,000,000	$7,400,000	$7,400,000	0.6209	$4,594,818
7	---	$6,300,000	$2,000,000	$8,300,000	$8,300,000	0.5645	$4,685,134
8	---	$7,200,000	$2,000,000	$9,200,000	$9,200,000	0.5132	$4,721,055
9	---	$8,100,000	$2,000,000	$10,100,000	$10,100,000	0.4665	$4,711,725
10	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.4241	$4,665,074
11	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.3855	$4,240,976
12	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.3505	$3,855,433
13	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.3186	$3,504,939
14	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.2897	$3,186,308
15	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.2633	$2,896,644
16	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.2394	$2,633,313
17	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.2176	$2,393,920
18	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.1978	$2,176,291
19	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.1799	$1,978,447
20	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.1635	$1,798,588
21	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.1486	$1,635,080
22	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.1351	$1,486,436
23	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.1228	$1,351,306
24	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.1117	$1,228,460
25	$9,460,000	$9,000,000	$2,000,000	$11,000,000	$20,460,000	0.1015	$2,077,214
26	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0923	$1,015,256
27	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0839	$922,960
28	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0763	$839,055
29	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0693	$762,777
30	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0630	$693,433
31	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0573	$630,394
32	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0521	$573,086
33	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0474	$520,987
34	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0431	$473,624
35	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0391	$430,568
36	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0356	$391,425
37	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0323	$355,841
38	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0294	$323,492
39	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0267	$294,083
40	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0243	$267,349
41	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0221	$243,044
42	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0201	$220,949
43	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0183	$200,863
44	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0166	$182,603
45	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0151	$166,002
46	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0137	$150,911
47	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0125	$137,192
48	---	$9,000,000	$2,000,200	$11,000,000	$11,000,000	0.0113	$124,720
49	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0103	$113,382
50	---	$9,000,000	$2,000,000	$11,000,000	$11,000,000	0.0094	$103,074
Total	$173,460,000	$409,500,000	$100,000,000	$509,500,000	$682,960,000		$252,844,023

Annualized Cost = $25,501,595

Cost per 1,000 gal delivered = $3.8389

Table A.5
Project 2 Costs with $0.03/kWh Energy

Year	Capital Cost	Annual Energy Cost	Other Annual O&M Costs	Total Annual O&M Costs	Total Costs	Discount Factor (i = 10%)	Present Worth Cost
1	$4,500,000	$140,000	$74,000	$214,000	$4,714,000	1.0000	$4,714,000
2	$4,500,000	$280,000	$148,000	$428,000	$4,928,000	0.9091	$4,480,000
3	$4,500,000	$420,000	$222,000	$642,000	$5,142,000	0.8264	$4,249,587
4	$4,500,000	$560,000	$296,000	$856,000	$5,356,000	0.7513	$4,024,042
5	$4,500,000	$700,000	$370,000	$1,070,000	$5,570,000	0.6830	$3,804,385
6	$4,500,000	$840,000	$444,000	$1,284,000	$5,784,000	0.6209	$3,591,409
7	$4,500,000	$980,000	$518,000	$1,498,000	$5,998,000	0.5645	$3,385,715
8	$4,500,000	$1,120,000	$592,000	$1,712,000	$6,212,000	0.5132	$3,187,738
9	$4,500,000	$1,260,000	$666,000	$1,926,000	$6,426,000	0.4665	$2,997,776
10	$4,500,000	$1,400,000	$740,000	$2,140,000	$6,640,000	0.4241	$2,816,008
11	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.3855	$825,063
12	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.3505	$750,057
13	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.3186	$681,870
14	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.2897	$619,882
15	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.2633	$563,529
16	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.2394	$512,299
17	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.2176	$465,726
18	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.1978	$423,388
19	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.1799	$384,898
20	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.1635	$349,907
21	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.1486	$318,097
22	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.1351	$289,179
23	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.1228	$262,890
24	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.1117	$238,991
25	$5,000,000	$1,400,000	$740,000	$2,140,000	$7,140,000	0.1015	$724,893
26	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0923	$197,513
27	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0839	$179,558
28	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0763	$163,234
29	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0693	$148,395
30	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0630	$134,904
31	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0573	$122,640
32	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0521	$111,491
33	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0474	$101,356
34	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0431	$92,141
35	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0391	$83,765
36	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0356	$76,150
37	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0323	$69,227
38	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0294	$62,934
39	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0267	$57,213
40	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0243	$52,011
41	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0221	$47,283
42	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0201	$42,985
43	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0183	$39,077
44	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0166	$35,525
45	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0151	$32,295
46	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0137	$29,359
47	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0125	$26,690
48	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0113	$24,264
49	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0103	$22,058
50	---	$1,400,000	$740,000	$2,140,000	$2,140,000	0.0094	$20,053
Total	$50,000,000	$63,700,000	$33,670,000	$97,370,000	$147,370,000		$46,633,451

Annualized Cost = $4,703,403

Cost per 1,000 gal delivered = $0.7080

Table A.6
Project 2 Costs with $0.12/kWh Energy

Year	Capital Cost	Annual Energy Cost	Other Annual O&M Costs	Total Annual O&M Costs	Total Costs	Discount Factor (i = 10%)	Present Worth Cost
1	$4,500,000	$580,000	$74,000	$654,000	$5,154,000	1.0000	$5,154,000
2	$4,500,000	$1,160,000	$148,000	$1,308,000	$5,808,000	0.9091	$5,280,000
3	$4,500,000	$1,740,000	$222,000	$1,962,000	$6,462,000	0.8264	$5,340,496
4	$4,500,000	$2,320,000	$296,000	$2,616,000	$7,116,000	0.7513	$5,346,356
5	$4,500,000	$2,900,000	$370,000	$3,270,000	$7,770,000	0.6830	$5,307,015
6	$4,500,000	$3,480,000	$444,000	$3,924,000	$8,424,000	0.6209	$5,230,641
7	$4,500,000	$4,060,000	$518,000	$4,578,000	$9,078,000	0.5645	$5,124,294
8	$4,500,000	$4,640,000	$592,000	$5,232,000	$9,732,000	0.5132	$4,994,055
9	$4,500,000	$5,220,000	$666,000	$5,886,000	$10,386,000	0.4665	$4,845,146
10	$4,500,000	$5,800,000	$740,000	$6,540,000	$11,040,000	0.4241	$4,682,038
11	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.3855	$2,521,453
12	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.3505	$2,292,230
13	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.3186	$2,083,846
14	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.2897	$1,894,405
15	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.2633	$1,722,186
16	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.2394	$1,565,624
17	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.2176	$1,423,295
18	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.1978	$1,293,904
19	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.1799	$1,176,276
20	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.1635	$1,069,342
21	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.1486	$972,129
22	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.1351	$883,754
23	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.1228	$803,413
24	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.1117	$730,375
25	$5,000,000	$5,800,000	$740,000	$6,540,000	$11,540,000	0.1015	$1,171,605
26	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0923	$603,616
27	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0839	$548,742
28	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0763	$498,856
29	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0693	$453,506
30	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0630	$412,278
31	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0573	$374,798
32	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0521	$340,725
33	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0474	$309,750
34	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0431	$281,591
35	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0391	$255,992
36	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0356	$232,720
37	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0323	$211,564
38	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0294	$192,331
39	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0267	$174,846
40	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0243	$158,951
41	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0221	$144,501
42	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0201	$131,364
43	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0183	$119,422
44	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0166	$108,566
45	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0151	$98,696
46	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0137	$89,724
47	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0125	$81,567
48	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0113	$74,152
49	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0103	$67,411
50	---	$5,800,000	$740,000	$6,540,000	$6,540,000	0.0094	$61,282
Total	$50,000,000	$263,900,000	$33,670,000	$297,570,000	$347,570,000		$78,934,828

Annualized Cost = $7,961,288

Cost per 1,000 gal delivered = $1.1984